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Environmental and Resource Conservation Considerations of Steel Industry Solid Waste

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16. ABSTRACT
The report examines the solid wastes generated by the iron and steel industry relative to the impact of Section 4004 of the Resource Conservation and Recovery Act. The quantities, properties, and origin of wastes which pose a potential problem are identified using flow diagrams, material balances, and generation factors. Of the estimated 140 million metric tons of solid waste (including inplant mill scrap) generated annually, 80% is either recycled or reused. Waste disposal practices are discussed, and the potential for groundwater pollution has been identified. The capital cost to collect leachate from nonhazardous wastes which could potentially endanger the groundwater was estimated to increase the current landfill costs by 40%; however, this cost was less than 1% of the estimated future overall environmental cost.

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Page	Correction
xii	Change Table 41 title to: "Permissible Criteria for Selected Components for Public Water Supplies."
9	Change last sentence of 2nd paragraph to: "This blast furnace slag is currently used primarily as road bed and construction fill."
10	Below Figure 2 title add: "(General College Chemistry, 3rd Edition, p. 542, by J.A. Babor and A. Lehrman. (T.Y. Crowell) Copyright 1929, 1940, 1951 by Harper & Row, Publishers, Inc. Reprinted by permission.)"
20	To Figure 7 title add: "© Rand McNally & Company, R.L. 79-Y-77."
33	In next to last sentence of 1st paragraph insert "in" between "waste" and "relation."
34	Change last sentence of 3rd paragraph to: "...industry will be only slightly increased by compliance with anticipated air and water regulations."
91	Substitute revised Table 41, attached.
95	In 2nd sentence of third paragraph change "In each" to "For each." Then add "This causes concern for the potential for groundwater endangerment."
	Change last sentence of 4th paragraph to: "...in Table 46 may require the use of a lined landfill wherever the leachate may endanger the groundwater."
114	Between the two sentences of the 3rd paragraph add: "This causes concern for the effect of leachate on the groundwater." Change the next sentence to "...have been identified in the extract of some of the various iron and steel wastes at concentrations greater than the permissible critieria."
	In the 2nd sentence of the 4th paragraph, change "would" to "could."
131	In Table 63 footnote change "Excluded" to "Included."
132	In Table 65 title change "Excluded" to "Included."
152	Below Figure 24 title add: "(M.M. Harris, "The Use of Steel Mill Waste Solids in Iron and Steelmaking." Copyrighted by American Iron and Steel Institute, 1978. Reprinted by permission.)"
164	Below Figure 25 title add: "(Iron and Steel Maker, October 1977)."

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171-173	Below Figure 26,27, and 28 titles add: "(Proceedings: Symposium on External Desulfurization of Hot Metal. Reprinted by permission McMaster University.)"
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by

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FOREWORD

The iron and steel industry generates a wide variety of solid wastes. Iron and steelmaking plants, containing process facilities such as coke plants, blast furnaces, steelmaking furnaces, and steel finishing operations, generate slags, sludges, scales, and dusts. The different types of solid waste which are generated vary widely in their potential environmental hazard.

As a result of implementation of the Clean Air Act, the Clean Water Act, the Resource Conservation and Recovery Act, and other Federal and State laws regarding public health and the environment, solid wastes have become an increasing concern. EPA is committed to a solid waste management program that will not only protect public health and the environment but will maximize the use/reuse of waste materials. Specifically, management technologies which recycle solid waste and thereby contribute to energy and resource conservation are actively encouraged.

The purpose of this report is to identify the origins, nature, and quantities of solid wastes generated in the iron and steel industry as well as characterize the current waste disposal practices and resource recovery potential of the wastes. Special emphasis has been given to potential changes and alternatives to current industry practice which may increase resource recovery and reduce the environmental impact of solid waste disposal.

Steffen Plehn
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ABSTRACT

This report examines the solid wastes generated by the iron and steel industry relative to the impact of Section 4004 of the Resource Conservation and Recovery Act. The quantities, properties, and origin of wastes are estimated using flow diagrams, material balances, and generation factors. Of the estimated 140 million metric tons of solid waste (including in-plant mill scrap) produced annually, 80 percent is either recycled or reused.

Waste disposal practices are discussed, and a potential for groundwater pollution is identified. The capital cost to collect leachate from non-hazardous wastes which could potentially endanger the groundwater is estimated to increase the current landfill costs by 40 percent, but this cost is less than one percent of the estimated future overall environmental cost.

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ABBREVIATIONS AND DEFINITIONS

BF	Blast Furnace
BFHM	Blast Furnace Hot Metal, i.e., molten iron as produced by the BF
BOF	Basic Oxygen Furnace
BOP	Basic Oxygen Process - refers to the BOF or Q-BOP method of steelmaking
EAF	Electric Arc Furnace
Megatonne	Specifies one million metric tons
OH	Open Hearth Furnace
Q-BOP	A special type of BOF with oxygen blown through holes in the bottom of the furnace
RCRA	Resource Conservation and Recovery Act of 1976
Tonne	Specifies a metric ton of 1000 kg

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John Ruppersberger served as the EPA Project Officer, a responsibility which was shared by OSW's Jan Auerbach and William Kline. The guidance and direction of these three individuals is gratefully acknowledged.

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1.0 SUMMARY

The iron and steel industry is characterized by the number of batch processes which are both labor and capital intensive. The decline in profit margins, together with the estimated cost of environmental control requirements, could limit the industry's ability to expand to meet the projected steel demand. The cost of environmental control requirements for air and water greatly exceed the current cost of environmental control for solid waste disposal facilities.

The iron and steel industry produces an estimated 140 million annual tonnes of waste (including metallic scrap) approximately 80 percent of which is currently either recycled or reused.

Large integrated iron and steel plants contain coke plants and blast furnaces which produce sludges, slags, dusts, and organic wastes. Also, these different wastes vary widely in their potential environmental hazard. For example, certain coke plant wastes are hazardous due to their polycyclic organic content, whereas the blast furnace slag is relatively inert. In addition, the form of the various wastes are distinctly different including scrap metal, bricks, slag, sludges, dusts, and liquids. Requirements for waste transportation and disposal as well as recycle and reuse depend upon these physical waste characteristics.

Most of the iron and steel wastes which are currently neither recycled nor reused are deposited in facilities which do not provide for leachate collection. Most of the disposition of nonhazardous waste is on-site with approximately 30 percent off-site and 6 percent handled by contract disposal. The groundwater under some of these sites is not suitable for drinking due to dissolved solids, oil, pH, ammonia, chromium, manganese, phenols, cadmium, and other components. Many of these components have been identified through various water extraction procedures on the individual wastes. The water extracts for almost every type of iron and steel waste contained materials which could make the groundwater unfit for human comsumption.

There are substantial differences in the landfill requirements for hazardous and nonhazardous wastes. Considering only the potential for groundwater endangerment at the property boundary (unfit for human consumption, among other criteria) of previously unendangered groundwater, a hazardous waste can possess a significant probability of groundwater endangerment, and liners are required for disposal. Some nonhazardous wastes may possess the potential for groundwater endangerment and landfill liners may be appropriate to protect the groundwater at those sites. If the management of the sanitary landfill elects not to use effective liners and groundwater monitoring indicates endangerment of the groundwater as a result of the landfill operations, either closure of the landfill site, corrective procedures, or legal exemption is required. Closure and corrective action are expensive alternatives and would tend to encourage the use of liners for some nonhazardous wastes.

The use of lined landfills for steel wastes with controlled discharge of the collected leachate was assumed for calculating Section 4004 compliance in this report, since this method of landfill operation would restrict the contamination of groundwater by the leachate. Excluding blast furnace slag, bricks, and rubble, proper landfill management under the Resource Conservation and Recovery Act of 1976 (RCRA) for nonhazardous wastes will increase the current cost of disposal ($58 million) by $21 million, an increase of 40 percent. This is less than one percent of estimated future air and water pollution controls. On this basis it is expected that the compliance of the steel industry with Section 4004 RCRA criteria will have little impact on overall steelmaking economics.

If the lined landfilling of steelmaking slag is required, this would increase disposal costs by $1.50 per tonne. This additional cost of disposal is comparable to the value of steel slags for construction purposes and should provide an additional economic incentive toward the use of steel slag rather than the disposal of it. Additional economic incentives for more extensive recycling of iron oxide wastes is also expected. The industry is also starting to direct its efforts toward some more basic changes in steelmaking which will provide more continuous processing and greater enclosure of the processes.

These improvements in steelmaking processes will increase the efficiency of production as well as reduce environmental problems including the generation of solid waste.

The iron and steel industry has accumulated enormous quantities of solid waste from its operations in former years. Because of the large volume involved, it would not be economically feasible to relocate these wastes to a lined landfill. The alternative would be to prepare the surface of the existing disposal pile in such a manner as to retard or prevent the infiltration of surface waters. Acceptable methods would include grading, paving, etc. Costs to accomplish this have not been included in the report because they will have to be determined on a site-by-site basis.

Iron oxide wastes create the most difficult disposal problems because of their physical size and chemical contaminants. At present, of the 14,000,000 tonnes generated annually, only 55 percent is recycled. The barrier to in-plant recycling is essentially that of economic feasibility. In certain portions of the country, regional treatment plants may be profitable; however, anti-trust regulations present a legal obstacle.

2.0 INTRODUCTION

The U. S. Environmental Protection Agency is required, under RCRA (PL 94580), to characterize and provide minimum criteria for industrial solid waste management practices. The study of the iron and steel industry is in support of these requirements.

In assessing the magnitude of the solid waste disposal problem and determining the areas of greatest urgency, several topical concerns must be addressed. These include:

1. Industry characteristics--the number of firms and plants, their size, location distribution, products, and general economic status.
2. Waste characteristics--identification and description of all wastes generated by the iron and steel industries including each waste stream and intermedia transfers and the use of this information in pinpointing a representative iron and steel plant.
3. Treatment and disposal--descriptions of present treatment and disposal practices, analysis of the prevalence of on-site vs. off-site disposal, assessment of the impact of Section 4004 RCRA criteria, the impact of current air and water regulations, and evaluation of alternative disposal practices for the industry.
4. Industrial waste recovery--identification of current practices and assessment of methods, including patents, in which industrial waste can be recovered, such as energy, raw material resource, etc., and volume of wastes produced, and/or alter its form so as to have a lesser impact on the environment, and enhance resource conservation and resource recovery.

3.0 CONCLUSIONS

1. Although most iron and steel wastes are not listed as hazardous, the available leachate testing data indicate that leachate control is needed to protect the groundwater for almost every type of iron and steel waste. The data indicate that leachate is produced which is unfit for human consumption and can, therefore, potentially endanger the groundwater.
2. Most iron and steel wastes are currently deposited in facilities which do not provide for leachate collection.
3. Proper landfill management under RCRA for nonhazardous iron and steelmaking wastes, using leachate collection would cost approximately 40 percent more than current landfill methods, but is relatively low in cost when compared to air and water pollution control.
4. There is substantial variability in the potential for environmental endangerment among the various producers within the same waste classification. This is consistent with differences in raw materials, process variables and type of product.
5. Technology has been developed to recycle or use most iron and steel wastes. Approximately 80 percent are currently either recycled or reused.
6. Iron oxide wastes present the greatest difficulties in recycling. Approximately 55 percent are currently recycled.

4.0 RECOMMENDATIONS

1. An investigation of the effects of raw material quality and process variables on iron and steel waste characteristics should be undertaken to identify the origins of the hazardous components of wastes. For example, alkali in ore can cause cyanide formation in the reducing conditions of blast furnace operation. A centrally sponsored program would avoid costly duplication of effort.
2. The organic components of certain iron and steel wastes which can be leached should be identified, due to the possibility of polycyclic organic materials in those extracts.
3. Sources of low volume, perhaps intermittent, wastes should be identified so that those wastes can be characterized.
4. Extraction testing should be conducted on iron and steel wastes. Current data are incomplete.
5. Hazardous wastes such as coke plant tar should not be placed with non-hazardous wastes in lined landfills. This practice could conceivably require expensive treatment of leachate and any liner failure could be hazardous.
6. Investigation into economical methods of accomplishing in-plant recycling of iron oxide wastes should be undertaken. Methods would include de-oiling the waste, dezincification, and agglomeration.
7. Legal barriers to regional plants for treating iron oxide wastes should be removed.

5.0 INDUSTRY CHARACTERIZATION

5.1 DESCRIPTION OF THE STEELMAKING PROCESSES

This study is concerned with the entire sequence of steelmaking operations beginning with the coke ovens and ending with hot and cold rolling into finished products.

Figure 1 is a flow diagram for a typical integrated 2.5 megatonne plant, that is, a plant producing 2.5 million metric tonnes of steel per year. Although ironmaking begins with the blast furnace, one of the raw materials charged into the blast furnace is coke and, therefore, the coke oven is indicated as the starting point for any sequential examination of the overall process.

Coking is carried out in brick ovens averaging 45 centimeters wide, two to six meters high and 10 to 15 meters long. Up to 100 ovens are built together forming a coke oven battery. Finely ground coal is charged into the oven through a system of fill holes, which are then sealed with lids. The charge is baked at about 1,100°C for about 18 hours. Volatile chemicals are removed from the coal and a porous solid mass of carbon remains. The chemicals driven from the coal exit the oven through standpipes. These pipes join a main which conveys the products to the gas by-product processing plant. Here the by-products are removed as oils, tars, pitch, and ammonia, and the cleaned gas is utilized as fuel. At the end of the cokemaking cycle, the doors are removed from the oven, the coke is pushed out and quenched with water. The processing and handling of coke produces a fine powder referred to as coke breeze. The coke itself presents no environmental problem, although certain plants have a solid waste problem with coke breeze when adequate facilities for utilizing it are unavailable. Significant hazardous waste problems arise in the coke by-product plant, however, where waste streams contain polycyclic aromatic compounds and other carcinogenic materials.[1]

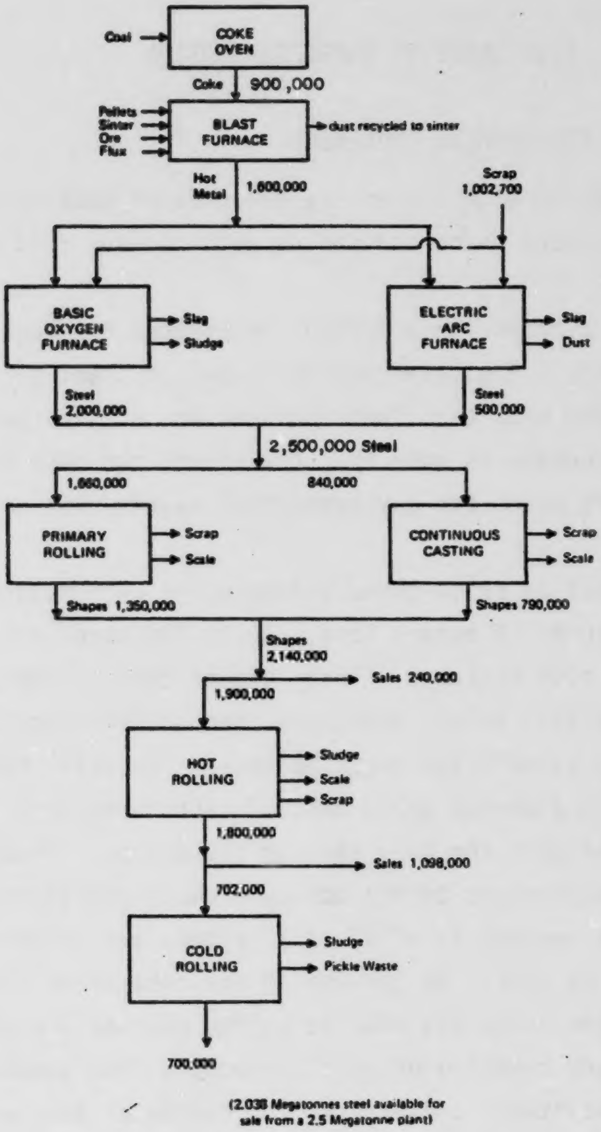

Figure 1. Flow diagram for a typical 2.5 Megatonne plant (all numbers in tonnes).

The blast furnace design in present use originated around 1870; however, operating practices in the past 20 years have changed, resulting in a tripling of its output. The greatest change is the utilization of sinter and pellets. Sinter is a mixture of powdered iron ore and other iron containing dust, limestone, and coke breeze burned on a moving grate, forming lumps of fused material suitable for blast furnace charging. Pellets are agglomerated pieces of iron ore or concentrate that can be sized before charging to the blast furnace.

The blast furnace is the ironmaking system for the steel plant. It is loaded from the top with pelletized iron ore, sinter, limestone and other fluxing substances, and coke (Figure 2). A blast of very hot air, sometimes enriched with oxygen and fuel oil or gas, is blown into the bottom of the furnace and a complex set of chemical reactions result in the production of molten iron containing 3 1/2 to 4 percent dissolved carbon. The molten product is blast furnace hot metal (BFHM). In some cases, BFHM is poured into molds to make small ingots of metal referred to as pig iron. The limestone and fluxing agents melt and react with or otherwise trap the sand, coal ash, and other impurities to form a slag that amounts to 20 to 40 percent of the quantity of metal produced. This blast furnace slag is currently used primarily as road bed and construction fill.

The blast of hot air through the furnace carries a great deal of dust out with it. This blast contains carbon monoxide and is valuable as a fuel. Utilization of the offgas as a fuel to preheat the blast air requires that the dust be completely removed, therefore, blast furnace dust does not appear as an uncontrolled emission. Since this dust contains many raw materials of value, it is recycled to the sinter plant where it is reincorporated with the raw material input to the furnace.

The steelmaking processes involve the removal of carbon from the blast furnace hot metal to below 2 percent, in some cases below one-tenth percent. It may also involve the addition of other metals to form specialized alloys. The major reactor for producing steel from hot metal is the basic oxygen furnace (BOF).

The BOF, a relatively recent development, is a pear-shaped vessel about 10 meters in diameter. The furnace is charged with up to 30 percent scrap

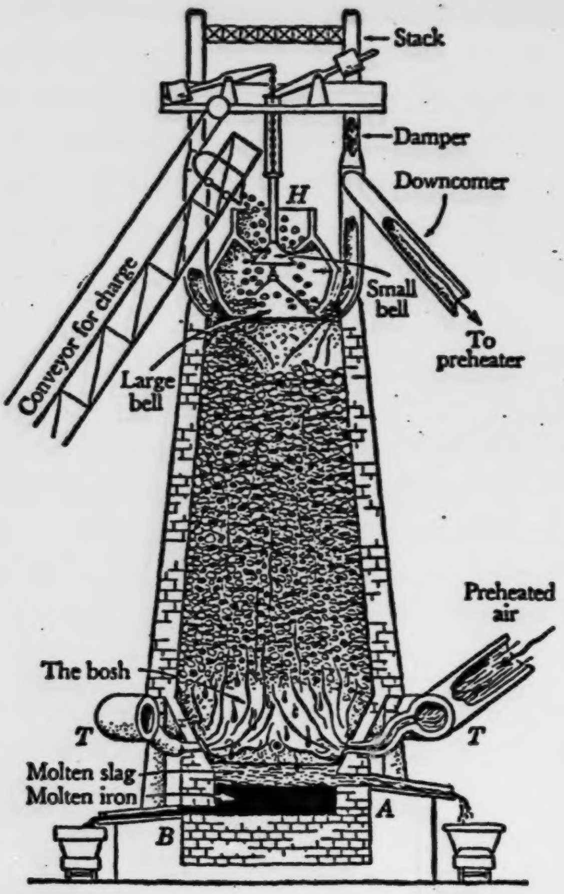

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Figure 2. Diagram of a blast furnace.[2]

metal, the balance being hot metal from the blast furnace, with some fluxing materials, as necessary. A lance is lowered to just above the surface of the metal, and oxygen is blown at supersonic velocities. In 12 minutes to an hour, depending on furnace design, the carbon, sulfur, and silicon are burned out of the hot metal and steel is formed. This process emits tremendous quantities of dust and fume and is equipped with air pollution controls. Dust laden air is collected in hoods and the dust is removed. If dry control techniques are utilized, the waste stream is in the form of dust. This dust is typically very fine and, therefore, difficult to recycle. If a wet control system is used, the dust appears as a sludge waste stream. The slag output of the BOF is a waste problem, as it is not immediately suitable for some construction fill purposes due to its potential for expansion. Often some of the slag is recycled to the blast furnace because of its iron, manganese, and lime content. The Q-BOP is a modification of the BOF, in which oxygen is blown through the metal from tuyeres located in the bottom of the furnace.

The electric arc furnace (EAF) is the second major producer of steel. This furnace is a refractory-lined vessel with three graphite electrodes mounted vertically that can be lowered into it. The EAF is a flexible device that can be utilized with oxygen lancing and other techniques to produce steels from scrap or hot metal, or to produce high purity steels and alloys. The majority of EAF charges do not involve hot metal but consist solely of scrap steel. A small amount of limestone flux is also added to the furnace, thereby producing a slag waste stream. Dust is evolved from the furnace to a degree that requires air pollution control equipment--usually a dry collection system. The EAF dust is apt to be particularly high in zinc and other toxic metals, thus causing difficulties in recycle and disposal.

Steel produced from iron and scrap metal is converted to a useable form by primary rolling, or continuous casting. If primary rolling is to be done the metal is cast into large ingots about 60 to 80 centimeters square and weighing 10 to 50 tonnes. The ingots are removed from their molds when they are solid but still hot and then placed into a soaking pit, a top opening type furnace. The bottom of this pit is covered with a layer of coke breeze before the ingot is put in. The steel ingot remains in this soaking pit until it is homogeneous in temperature. Then it is removed and sent to primary rolling. Soaking pit slag is formed by metal oxides that flake off the ingot and fuse with the coke breeze. It is removed periodically and landfilled. This slag is not comparable with ironmaking or steelmaking slag in that it is composed of metal oxides and carbon.

Primary rolling converts the hot steel ingot into a form that can be further processed: into slabs 60 to 150 centimeters wide and 5 to 23 centimeters thick; billets (5 by 5 to 13 by 13 centimeters); or blooms (15 by 15 to 30 by 30 centimeters). Bars can also be produced and the metal can be sent directly to rolling mills for producing structural shapes. During primary rolling, high pressure water sprays remove the oxide film that continuously forms on the red hot metal and also cool the rollers. These sprays produce waste scale and sludge. The scale consists of large pieces of iron oxide that have sloughed off the ingot. These are usually returned to the blast furnace as raw material. Sludge consists of very fine pieces of iron oxide dispersed in the water used for cooling and cleaning the metal.

In the primary rolling process the ends of the slabs or billets are metallurgically defective and are cut off. This amounts to eight or more percent of the metal becoming scrap. The final product of primary rolling is usually cooled and stockpiled for further processing according to facilities and market needs.

Continuous casting is the alternative method of producing shapes from liquid steel. This method is becoming popular because it produces a higher yield of steel product than with primary rolling, about 94 percent compared to 81 percent. As a result, the waste stream is accordingly smaller. In continuous casting, the molten steel is poured into a small ladle or tundish. A continuously controlled valve in the bottom of the tundish pours the metal into a water-cooled mold--usually made of copper. The metal solidifies along the surfaces of this mold and slides out of it through a system of guide rollers where it is further cooled with water sprays thereby producing either a billet or a slab. After solidification, the metal is cut into lengths by traveling torches, and sent to cooling racks to cool to room temperature. The waste stream output from this process consists of scrap and scale, since the metal always continues to oxidize to iron oxide while hot. This scale is smaller than that from primary rolling and usually ends up in a sludge with the cooling water.

Nearly 90 percent of the shapes produced by primary rolling or continuous casting are processed further by hot rolling. The stored slabs or billets are transferred to the hot rolling mill where the first operation is to reheat them in a furnace to a temperature that allows flexibility for shaping. After reaching a suitable temperature, around 1200°C, the steel is transferred to the rolling mills and further squeezed to the desired shape and dimension. Since the metal is hot and continuously oxidizes, the process of scale removal with high pressure water streams is again employed. The result is a waste stream of scale and sludge as in the case of primary rolling. The sludge produced is often contaminated with oil from the pressurized lubrication system on the bearings of the rollers. Trimming and cutting also produce scrap in this operation. About 50 percent of the output from the hot rolling mill is in a form desired by some customers and is sold at this point. The remainder proceeds to a cold rolling operation.

The hot rolled steel has a black to gray-black coating of iron oxide on its surface. Before cold rolling can be pursued, this oxide coating must be removed. This is done by a process called pickling in which the metal is dipped into sulfuric or hydrochloric acid. For example, coils of 0.3 to 0.6 centimeter thick steel sheet, weighing about 30 tonnes, are unrolled and welded into a continuous strip which passes through the pickle tanks. The metal travels about 122 meters (400 feet) in a vat of acid at about 6 meters per second (1100 feet per minute) if hydrochloric acid is used, or about half that speed if sulfuric acid is used. At the end of the pickle line, the metal is rerolled into coils which are then sent on to the cold rolling mill. The pickling operation produces waste acid, referred to as spent pickle liquor, which has 10 to 25 percent iron in the solution. This is a problematical waste stream as it produces a large quantity of gelatinous sludge if it is neutralized. A large pickling line may produce as much as 500 liters (130 gallons) of spent acid per minute, 24 hours a day.

Cold rolling accomplishes three things. First, the metal is reduced to the thickness desired by the customer; second, the metal acquires a smooth desirable surface finish and third, the cold metal is hardened by a metallurgical transformation. The rolling operation generates heat requiring that the rollers and the metal be cooled with water. In this case, plain water cannot be used but rather an emulsion of oil and water is required. The cooling water must be processed to remove tramp oil and also some sludge. The quantity of the sludge produced is a very small fraction, less than one percent of that produced by hot rolling. After the cold rolling process, the product usually goes directly to the customer unless it is to be given further finishing with zinc, tin, or other coatings.

5.2 INDUSTRY OVERVIEW

5.2.1 Number of Plants

By updating information contained in the 1977 Directory of Iron and Steel Works,[3] the EPA Effluent Guidelines 1977 Industry Survey,[4] and by drawing upon other information on sinter plants,[5] estimates of the numbers of operating plants in the U.S. in 1977 were obtained. There were 169 operating plants making either iron or steel or both. There were 153 plants making steel using either hot metal and scrap steel or just scrap steel. There were 28 integrated plants that is, plants making coke, sinter, iron and steel, and operating rolling mills. There are 19 major and 72 smaller firms (91 total) engaged in iron and steelmaking.

Table 1 provides estimates of the number of plants at which each of the basic operations (coking, sintering, blast furnace ironmaking, and steelmaking) are conducted together with the estimated total annual capacity. This Table also shows that 50 plants were using continuous casting in 1977.

TABLE 1. CAPACITY ESTIMATES BY PROCESS

Process	No. of Plants	Estimated Capacity (megatonnes/yr)
Coke	46	58.4
Sinter	35	50.2
Blast Furnace (BF)	57	95.0
Basic Oxygen Furnace (BOF)	35	88.3
Open Hearth Furnace (OH)	19	22.9
Electric Arc Furnace (EAF)	120	31.8
Continuous Casting	50	21.3

5.2.2 Size and Capacity Distribution

Statistical investigation of the plant size and capacity distributions shows that the industry is divided into two distinctly different processing types: relatively small plants with EAF's and large complexes with BOF's, and some open hearths. For this reason, separate distributions have been developed for those two types and are shown in Figure 3 for use in determining either the percent of total plants or the percent of total capacity less than the indicated size. The frequency distributions shown are log-normal.

Figure 4 shows, by Corporation, the size distribution of the plants that account for approximately 90 percent of national capacity. Capacity accounted for by the integrated steel companies is shown in Figure 5, along with that of plants with only EAF's. The latter collectively provide a significant portion of national capacity and industry solid wastes.

Raw steel capacity by EPA region is shown in Figure 6.

In Summary: Two large corporations, U.S. Steel and Bethlehem account for 35.6 percent of national capacity; five medium-sized corporations (LTV, Republic, National, Armco, and Inland) account for 36 percent; small corporations and miniplants account for 28 percent.

5.2.3 Geographic Location of Plants

Figure 7 geographically displays U.S. steelmaking facilities with the number of plants in each state identified. Pennsylvania, Ohio, and Indiana account for 54 percent of the total capacity; Illinois and Michigan account for 18 percent. Alabama, California, Colorado, Kentucky, New York, Texas, Utah, and West Virginia account for 24 percent. Remaining states collectively represent less than 5 percent.

5.3 GENERAL ECONOMIC STATUS OF THE INDUSTRY

The general economic status of the iron and steel industry is an important factor to be considered in implementing adequate control and resource recovery practices. The industry's cash flow, used for capital expenditures, dividends, and debt reduction, has declined relative to other industries since 1974, and in 1976, measured only 132 percent of its 1967 value (Figure 8). In contrast, the Standard and Poor's 400 Industries collectively measured 200 percent of their 1967 value, and the paper industry measured 218 percent of its 1967 value.[6] Cash flow is defined as net earnings plus depreciation and amortization.

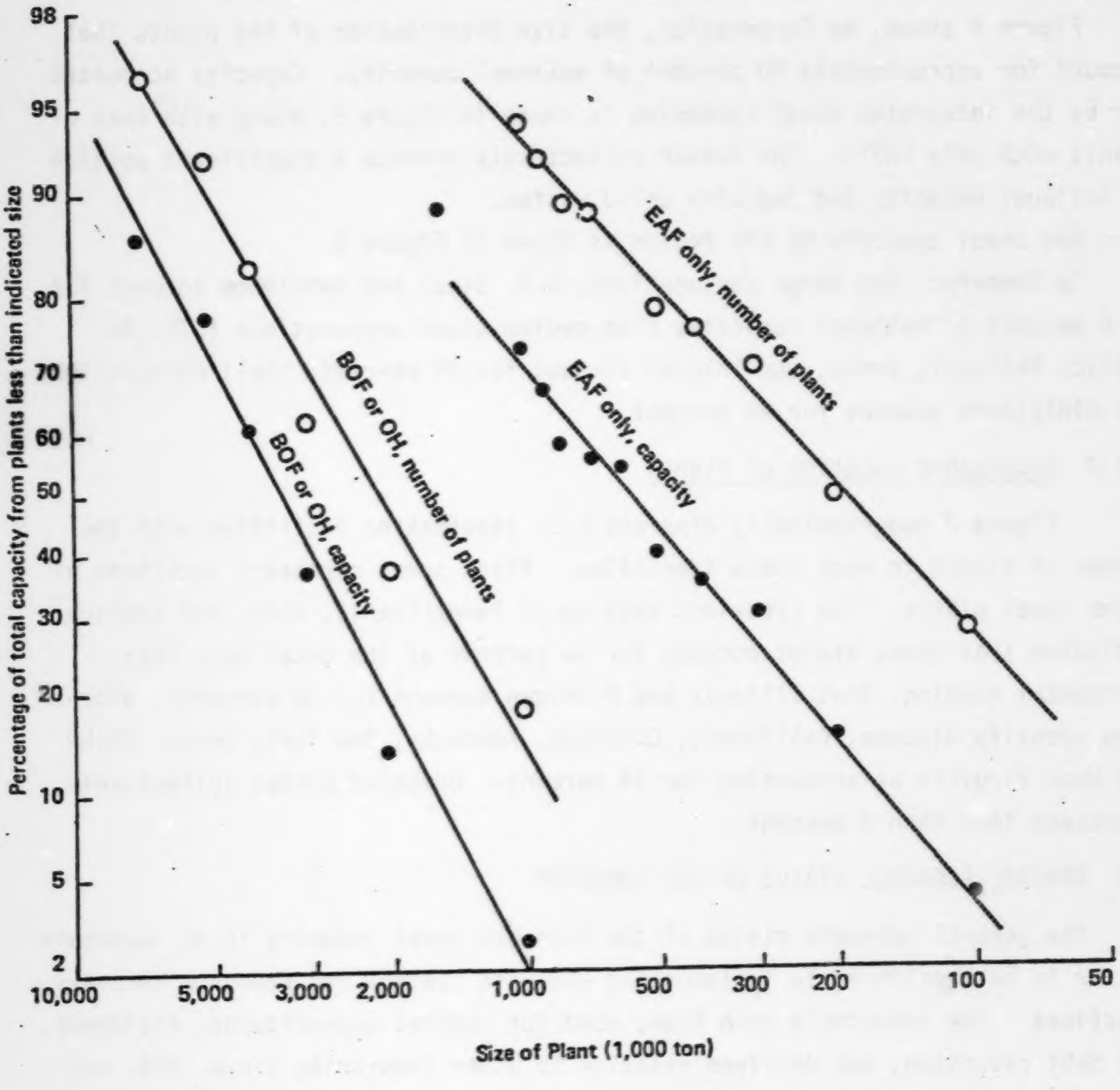


Figure 3. Size and capacity cumulative distributions for two types of steel plants.

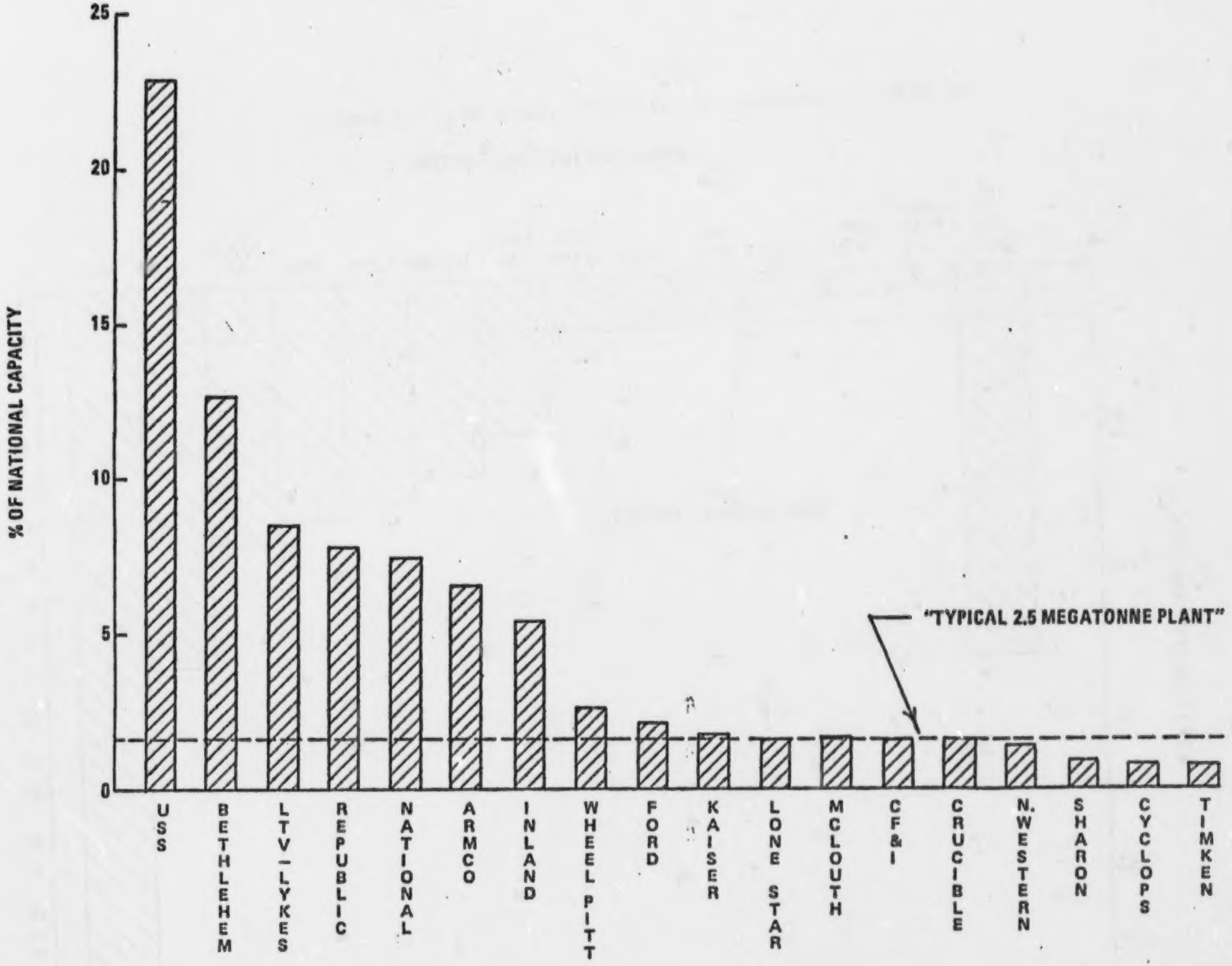


Figure 4. Size distribution of companies that account for ~ 90% national capacity (raw steel) by company.

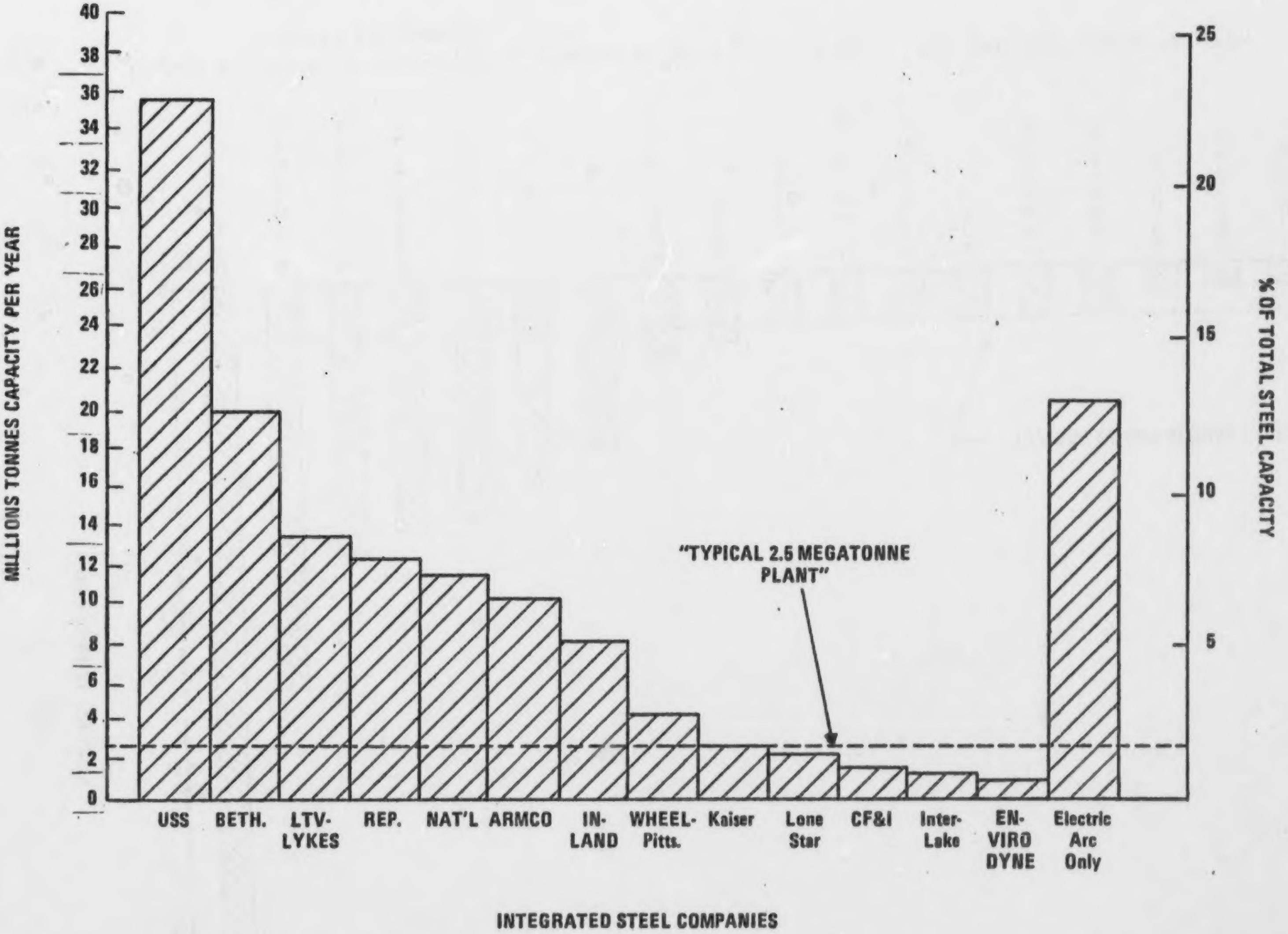


Figure 5. Raw steel capacity of integrated companies.

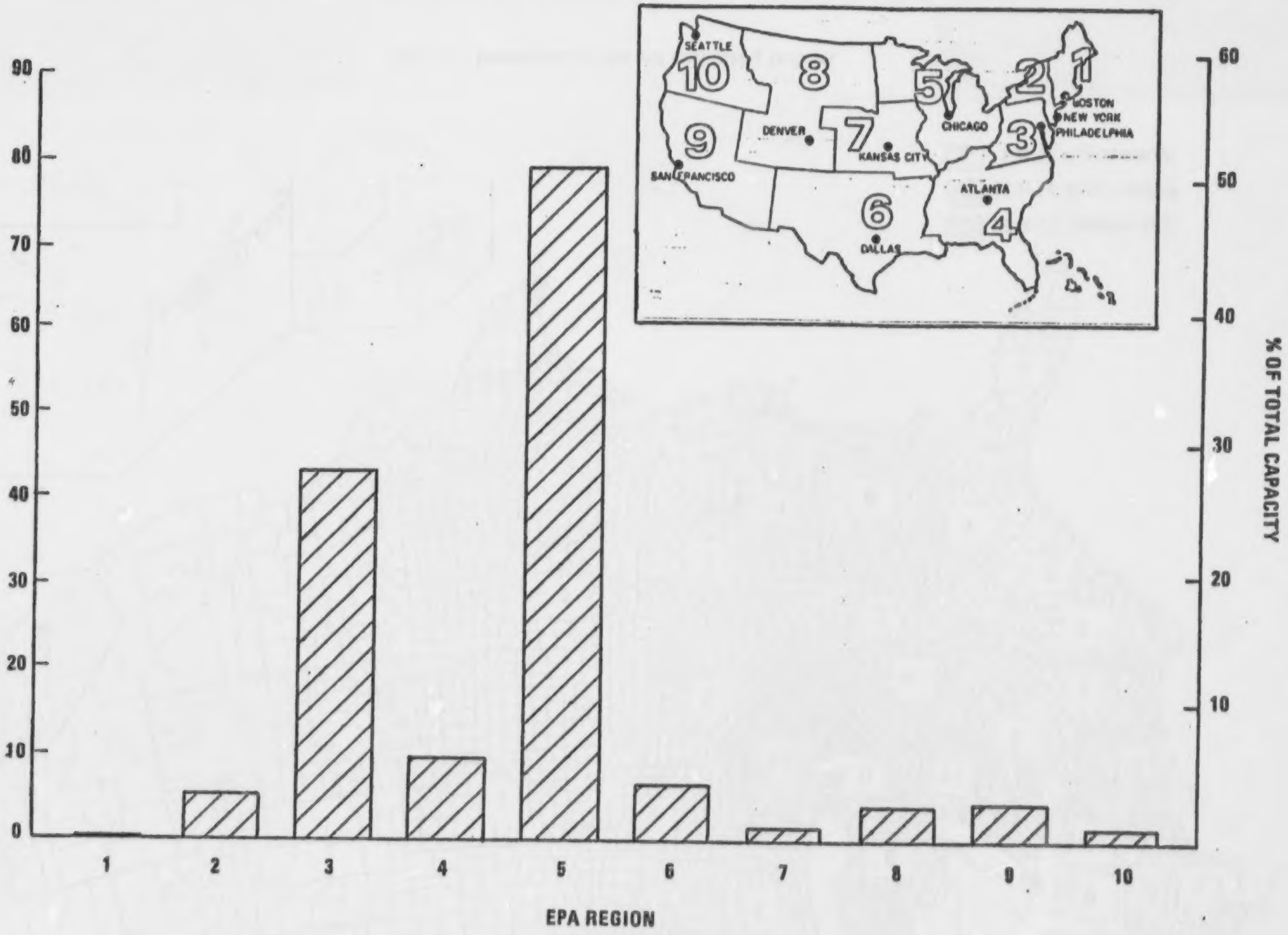


Figure 6. Raw steel capacity by EPA Region.

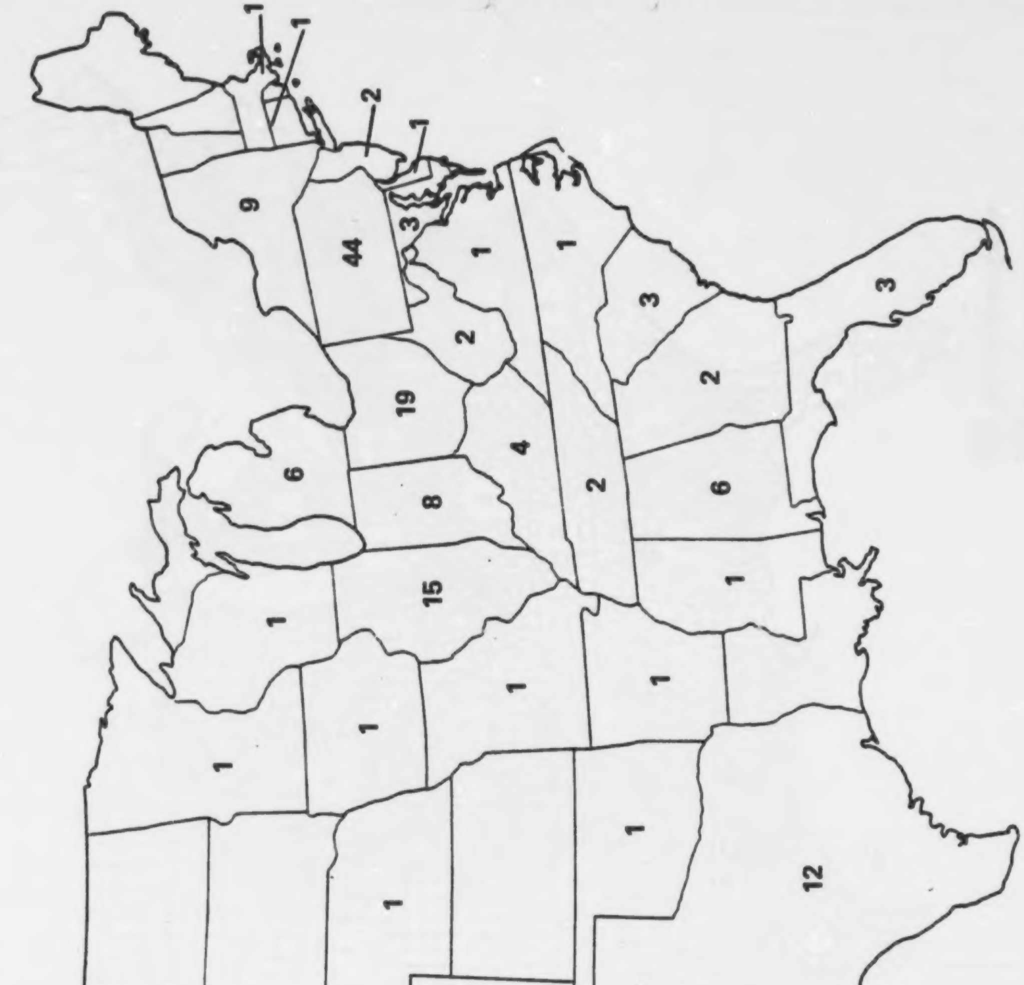


Figure 7. Distribution of iron and steelmaking facilities.

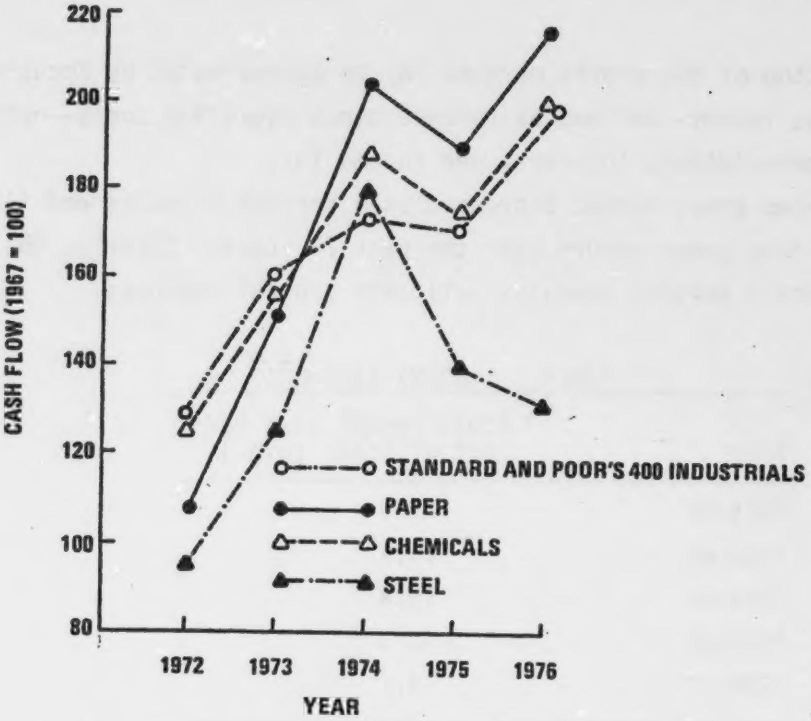


Figure 8. Cash flow of the steel industry compared to other industries.[6]

The decline in cash flow coincides with a corresponding drop in capacity utilization from 97 percent in 1974 to 76 percent in 1975, 81 percent in 1976, and 78 percent in 1977.

Profit margins in the steel industry have declined in recent years due to rapidly rising costs, increased imports, low capacity utilization due to decreased sales, and price increases that did not correspond to the increased costs of production. Production costs in 1977 rose 8 percent over 1976 while product prices increased only 5 percent.[7]

Production costs and finished steel price increases from 1972 through 1977 were as follows:[8]

Coal	138%
Iron Ore	76%
Steel Scrap	133%
Labor	82%
Energy	166%
Finished Product	79%

The reduction of the profit margins may be approximated by focusing on the decline of gross income--defined as revenue minus operating costs--before the deduction of depreciation, interest, and income tax.

Table 2 shows gross income expressed as a percent of sales and illustrates the decline in this gross return over the past 20 years. Clearly, the trend of declining in profit margins predates pollution control expenses.

TABLE 2. GROSS INCOME[8,9]

Years	Gross Income as a Percent of Sales (avg.)
1955-59	19.0
1960-64	16.6
1965-69	15.4
1970-74	12.3
1975-77	9.7

Imported steel has decreased the share of the U.S. market for the domestic steel industry and, at the same time, has restricted price increases. Imports are expected to fall off in 1978 as the trigger pricing mechanism takes effect.[10]

Table 3 presents the quantity of imported steel, as a percentage of domestic production, for the period 1973-1978.

TABLE 3. IMPORTS: % OF DOMESTIC CONSUMPTION[10]

Year	1973	1974	1975	1976	1977	1978 EST.
%	12.4	13.4	13.4	14.1	17.8	14.5

Predictions for the near term, from Standard and Poors' Industry Surveys, are for a profit gain in 1978, but the improvements are expected to fall short of what is considered to be required for modernization, expansion, and dividends. A further improvement is expected through 1979 if the economy does not slip into a recession and steel imports do not rebound.[10]

A summary of the financial statements of companies representing approximately 90 percent of the raw steel production is provided in Table 4 and underscores the recent profit squeeze faced by the steel industry.

TABLE 4. SUMMARY OF FINANCIAL STATEMENTS* (ALL DOLLARS IN MILLIONS)[9]

	1977	1976	1975	1974	1973
REVENUE	39,787.4	36,462.4	33,676.3	38,243.6	28,863.2
Employment Costs	14,418.6	13,273.6	11.883.1	11,858.5	10,201.3
Materials, Supplies, etc.	22,129.0	19,175.7	17,373.6	19,900.3	14,450.5
Depreciation, amortization	1,528.5	1,378.4	1,272.8	1,327.2	1,262.6
Interest on long term debt	594.3	480.7	382.5	353.7	357.4
Taxes other than income	597.1	560.8	515.7	482.6	452.5
Income taxes	(452.4)	265.7	653.7	1,846.1	866.7
(Gain) loss on discontinued operations, sales of assets	949.1	(9.9)	---	---	---
TOTAL COSTS	39,764.2	35,125.0	32,081.4	35,768.4	27,591.0
Net Income	23.2**	1,337.4	1,594.9	2,475.2	1,272.2
% of Revenue	0.06	3.7	4.7	6.5	4.4
Current Assets $	12,356.6	11,828.6	10,750.4	12,212.5	9,512.2
Current Liabilities	6,800.6	6,114.5	5,311.2	6,729.5	4,965.0
Total Assets	35,413.7	33,564.0	30,419.9	29,506.4	26,132.7
Total Liabilities	17,776.3	15,536.7	13,227.7	13,263.2	11,619.2
Equity	17,637.4	18,027.3	17,192.2	16,243.2	14,513.5
Current Assets/Current Liabilities	1.82	1.70	1.88	1.81	1.92
Liabilities/Equity	1.01	0.86	0.77	0.82	0.80
CAPITAL EXPENDITURES	2,857.6	3,252.9	3,179.4	2,114.7	1,399.9

*Companies representing 90 percent of raw steel production.

**Reflects substantial impact of permanent plant closings.

5.3.1 Capital Expenditures By The Steel Industry

Capital expenditures for replacement and modernization, modest capacity increase, and pollution abatement will approximate $3 billion per year through 1980.[8] An AISI-funded study by the A. D. Little Company[11] estimates a capital cost of $24 billion for 1978-1985 to replace 40 million tonnes of raw steel capability based on a historical replacement rate of 3.5 percent. However, this report adds to the $24 billion estimate the cost of environmental control requirements for air and water, which increases the 8 year total to $28.9 billion with no growth in capacity. Based on the results of 1973-1977, cash flow from net profits and depreciation would be $26.4 billion so that, with no growth, the industry would fall short of capital, via internal generation, by about $2.5 billion.[11]

5.3.2 Status of the Six Largest Integrated Steel Producers

The six corporations with the greatest raw steel capacity are listed in this section as U.S. Steel, Bethlehem, National, Republic, Armco, and Inland. These companies accounted for nearly two-thirds of 1977 raw steel production.

Table 5 is a comparative financial summary of the six corporations. These data are used in compiling Table 6, which provides financial ratios for the six companies, for all reporting companies, and for the whole industry (from Dun's review) for comparison.

However, with the recently approved merger of Lykes-Youngstown with LTV Corporation (Jones and Laughlin Steel), the resulting corporation has a raw steel capacity that ranks third nationally. Financial information on this new corporation is not included due to a lack of comparative data.

Brief descriptions of company employment and capital spending projects follows.

U.S. Steel

U.S. Steel produces steel at 13 locations with a total corporate employment of 165,845 in 1977. The company is engaged in extensive planning for a new location in northwestern Ohio with a capacity of 2.73 million net tonnes per year. The investment cost is estimated at $1,430 per annual tonne

TABLE 5. FINANCIAL SUMMARY OF SIX INTEGRATED STEEL COMPANIES[5,12]
(all dollars in millions)

	Year	USS	Bethlehem	National	Republic	ARMCO	Inland
Net Sales	77	9609.9	5370	3138.9	2909.4	3549.2	2681.6
	76	8607.8	5248	2840.5	2545.6	3151.0	2388.2
Operating Margin[a]	77	1665.4	506.8	347.9	427.3	415.7	391.9
	76	1887.7	762.1	343.0	390.6	390.7	431.9
Net Income	77	137.9	(18.7)	60.1	41.0	119.8	87.8
	76	410.0	168	85.7	65.9	123.7	104.0
Capital Expenditure	77	864.7	551.9	161.7	155.5	146.4	282.0
	76	957.3	406.6	270.9	248.7	272.0	303.8
Total Assets	77	9914.4	4898.9	2827.6	2406.3	2882.8	2302.4
	76	9167.9	4977.5	2798.0	2333.1	2833.6	2070.1
Current Assets	77	3040.3	1495.7	989.2	834.7	1053.8	691.4
	76	2791.2	1615.2	995.5	788.2	1039.9	627.9
Current Liabilities	77	1712.5	978.5	554.6	384.4	577.3	364.7
	76	1637.4	822.5	574.8	434.4	509.5	324.5
Total Liabilities	77	4772.7	2720.0	1546.6	1072.3	1419.8	1155.7
	76	4038.9	2284.9	1534.9	1014.2	1427.5	965.5
Short Term Debt	77	250.0	3.3	19.3	17.8	110.3	13.2
	76	195.3	12.9	21.8	13.9	139.2	11.0
Long Term Debt	77	2550.2	1154.8	722.3	452.3	643.0	614.0
	76	1959.9	1023.1	743.8	372.2	667.2	480.5
Total Debt	77	2800.2	1158.1	741.6	470.1	753.3	627.2
	76	2155.2	1036.0	765.6	386.1	806.4	491.5
Net Worth (Equity)	77	5141.7	2178.9	1281.0	1334.0	1463.0	1146.7
	76	5129.0	2692.6	1263.1	1318.9	1406.1	1104.7
Invested Capital[b]	77	7941.9	3337.0	2022.6	1804.1	2216.3	1773.9
	76	7284.2	3728.6	2028.7	1705.0	2212.5	1596.2

[a] Revenue from sales minus manufacturing expense

[b] Net worth plus total debt

TABLE 6. COMPARISON OF FINANCIAL RATIOS[5,12]

		USS	Bethlehem	National	Republic	ARMCO	Inland	90% of Industry[a]	Dun's Review (Dec. 1977)[b]		
$\frac{\text{Current Assets}}{\text{Current Debts}}$	1977	1.78	1.53	1.78	2.17	1.83	1.90	1.82		–	
	1976	1.70	1.96	1.73	1.81	2.04	2.13	1.70	(3.01)	2.25	(1.80)
$\frac{\text{Net Profits}}{\text{Net Sales}}$ X 100	1977	1.4	(0.3)[c]	1.9	1.4	3.4	3.3	2.4[c]		–	
	1976	4.8	3.2	3.0	2.6	3.9	4.4	3.7	(5.7)	4.1	(2.2)
$\frac{\text{Net Profits}}{\text{Net Worth}}$ X 100	1977	2.7	(0.9)	4.7	3.1	8.2	7.7	5.5[c]		–	
	1976	8.0	6.2	6.8	5.0	8.8	9.4	7.4	(15.1)	9.1	(6.2)
$\frac{\text{Liabilities}}{\text{Net Worth}}$	1977	0.93	1.25	1.21	0.80	0.97	1.01	1.01		–	
	1976	0.79	0.85	1.22	0.77	1.02	0.87	0.86	(0.60)	0.83	(1.25)
Operating Profit (millions of dollars)	1977	743.9	294.5	319.7	245.8	325.2	256.4	–		–	
	1976	1030.2	561.4	327.5	217.8	294.3	300.7	–		–	
Capital Expenditures (millions of dollars)	1977	864.7	551.9	161.7	155.5	146.4	282.0	–		–	
	1976	957.3	406.6	270.9	248.7	272.0	303.8	–		–	
Planned Capital Expenditures (millions of dollars)	1978	NA	500	NA[d]	225	121.0	290	–		–	

---

[a] Represents companies with 90% of raw steel production[4]

[b] Represents 52 companies of blast furnaces, steel works, and rolling mills; the middle number represents the median, and the numbers in parenthesis represent the upper and lower quartile.[14]

[c] Excluding pretax losses from plant closings

[d] NA = Not Available

(including raw materials, transportation, and support facilities). The company reportedly awaits a cost-price relationship suitable to justify the investment.

Recently completed projects include installation of two EAFs, two slab casters, a plate mill, rehabilitation of five coke oven batteries, blast furnace enlargement at Braddock, PA, a new pipe mill, and an electrogalvanizing facility. Planned projects include a 182 tonne Q-BOP and a 4,545 tonne per day blast furnace at Fairfield, Alabama, air and water quality control facilities, taconite expansion, hot strip mill, coke oven gas processing facility, a new coke oven battery, rehabilitation of two more coke batteries, and boiler emission control facilities.[12]

TABLE 7. UNITED STATES STEEL ($MM)[7,12,13]

	1st Quarter 1978	1977	1976	1975	1974
Sales	2,427.9	9,610	8,608	8,171	9,140
Operating Profit	68.9	743.9	1,030.2	1,170.8	1,537.4
% of Sales	2.8	7.7	12.0	14.3	16.7
Pretax Profit (Loss)	(91.7)	101.8	518.3	823.6	1,033.3
% of Sales	(3.8)	1.1	6.0	10.1	11.2
Net Income (Loss)	(58.7)	137.9	410.3	559.7	630.4
% of Sales	(2.4)	1.4	4.8	6.9	6.9
Capital Expenditures	---	864.7	957.0	787.4	508.3
Raw Steel (million tonnes)	---	26.2	25.7	24.0	30.8
% of Industry	---	23.1	22.1	22.6	23.3

Bethlehem Steel

Bethlehem operates eight steel producing plants. A partial shutdown was announced at the end of 1977 due to a reduction in capacity at the Lackawanna, N.Y. plant from 4.4 to 2.5 million tonnes per year, and at the Johnstown, Pa. plant from 1.6 to 1.1 million tonnes per year, resulting in a reduction of employment to 93,000 persons. Competition from imports, flood damage (Johnstown), and marginal operations where investment to modernize and add pollution control equipment could not be justified were cited as reasons for the shutdowns.

Projects include a new basic oxygen furnace at Burns Harbor, a blast furnace at Sparrows Point, a scrap melter at Lackawanna, a novel coke quench car, two water treatment plants, a new bar mill, and a new plate mill. Planned capital expenditures were cut by $128 million in 1977.[12]

TABLE 8. BETHLEHEM STEEL ($MM)[7,12,13]

	1st Quarter 1978	1977*	1976	1975	1974
Sales	1,380.9	5,370.0	5,248.0	4,977.2	5,381.0
Operating Profit	97.7	294.5	561.4	597.6	866.3
% of Sales	7.0	5.5	10.7	12.0	16.4
Pretax Profit (Loss)	1.1	(120.3)	194.0	283.0	616.1
% of Sales	0.0	(2.2)	3.7	5.4	11.4
Net Income (Loss)	1.1	(18.7)	168.0	242.0	342.0
% of Sales	0.0	(0.3)	3.2	4.9	6.4
Capital Expenditures	---	551.9	406.6	674.3	524.2
Raw Steel (million tonnes)	---	15.1	17.2	15.9	20.3
% of Industry	---	13.3	14.7	15.0	15.3

*Before nonrecurring writeoff of $791 million before taxes.

National Steel

National Steel has three basic steel producing plants with approximately 36,000 employees. Projects underway include a water quality control system, coke battery improvements, and blast furnace rebuilding at the Weirton, W.Va. plant, a continuous slab caster at the Great Lakes Division, a wastewater treatment plant, a novel coke pushing emission control system, and new coke oven facilities at Granite City.[12]

Republic Steel

Republic Steel has six steelmaking plants with a total corporate employment of 41,000. Two bottom blown basic oxygen furnaces (Q-BOP) were recently installed at the Chicago plant and marked the end of open hearth steel production for Republic. Other projects include a continuous silicon annealing line, 10 high speed grinders with air pollution controls to eliminate scarfing at the Canton, Ohio plant, and a suppressed combustion air cleaning system for the basic oxygen furnaces at Cleveland.[12]

TABLE 9. NATIONAL STEEL ($MM)[7,12,13]

	1st Quarter 1978	1977	1976	1975	1974
Sales	846	3,138.9	2,840.5	2,241.2	2,727.8
Operating Profit	50.4	319.7	327.5	174.6	427.4
% of Sales	6.0	10.1	11.5	7.8	15.7
Pretax Profit	1.6	68.2	95.0	63.6	334.4
% of Sales	0.0	2.2	3.3	2.8	12.3
Net Income	2.4	60.1	85.7	58.1	175.8
% of Sales	0.2	1.9	3.0	2.6	6.4
Capital Expenditures	---	161.7	270.9	313.3	182.0
Raw Steel (million tonnes)	---	8.5	9.8	7.8	9.6
% of Industry	---	7.5	8.4	7.4	7.3

TABLE 10. REPUBLIC STEEL ($MM)[7,12,13]

	1978	1977	1976	1975	1974
Sales	831.2	2,904.4	2,545.6	2,333.3	2,741.4
Operating Profit	61.9	245.8	217.8	251.1	438.7
% of Sales	7.4	8.4	8.6	10.8	16.0
Pretax Profit	31.8	41.6	41.0	91.4	298.6
% of Sales	3.8	1.4	1.6	3.9	10.9
Net Income	9.8	41.0	65.9	72.2	170.7
% of Sales	1.2	1.4	2.6	3.1	6.2
Capital Expenditures	---	155.5	248.7	200.0	102.5
Raw Steel (million tonnes)	---	8.4	8.7	8.0	9.6
% of Industry	---	7.4	7.5	7.5	7.3

Armco Incorporated

Armco has eight steel producing plants with 33,000 employees. In 1977, steel accounted for 68 percent of corporate sales and 41 percent of the operating profits. Net income as percent of sales has ranged from 3.4 to 3.9 percent for 1975-1977, down from 6.4 percent in 1974.

Recently completed capital projects include melting, casting, and billet facilities at Kansas City, Mo., argon oxygen reactor at Butler, Pa., and a coal mine and processing plant in West Virginia. Appropriations have been approved for hot metal desulfurization at Ashland, Ky., a fine coal cleaning circuit at Big Mountain Coal, Inc., and expansion of Union Wire Rope facilities. Capital expenditures have been used with emphasis on modernization instead of expansion.[12]

TABLE 11. ARMCO, INC. ($MM)[7,12,13]

	1st Quarter 1978	1977	1976	1975	1974
Consolidated:					
Sales	946.2	3,549.2	3,151.0	3,046.8	3,190.1
Operating Profit	86.1	325.2	294.3	368.3	512.6
% of Sales	9.1	9.2	9.3	12.1	16.1
Pretax Profit	45.3	121.1	116.0	172.1	351.7
% of Sales	4.8	3.4	3.7	5.6	11.0
Net Income	30.2	119.8	123.7	116.7	203.6
% of Sales	3.2	3.4	3.9	3.8	6.4
Capital Expenditures	---	146.4	272.0	255.5	104.6
Steel Alone:					
Sales		3,399.4	2,093.8	1,956.6	2,202.4
Operating Profit		176.5	150.3	170.0	396.1
% of Sales		7.3	7.2	8.7	18.0
Net Income		86.3	51.2	12.0	112.7
% of Sales		3.6	2.4	0.6	5.1
Capital Expenditures		98.1	236.1	212.5	81.3
Raw Steel (million tonnes)		7.2	6.8	6.4	8.1
% of Industry		6.2	5.8	6.0	6.1

Inland Steel

Inland Steel's only producing plant is their Indiana Harbor Works in East Chicago, Indiana. Total employment at Inland is 35,200. 79 percent of the company's steel is shipped to the surrounding five state areas--Illinois, Indiana, Ohio, Michigan, and Wisconsin.

Inland is presently in the middle of a $2 billion expansion program started in 1974 and continuing through the mid 1980's that is designed to increase raw steelmaking capacity by 2.3 million annual tonnes. The first phase of $800 million expenditure is scheduled for completion in 1979 and includes a new blast furnace, coke oven battery, boiler-blower house, environmental controls, and raw materials facilities. This will result in a 1.0 million tonne increase in capacity. The second phase of $1.2 billion will include a plate mill, improvement to the hot strip mill and BOF, a coke oven battery, and slab casting machine. A 1.3 million tonne increase in capacity is expected from the second phase.[12]

TABLE 12. INLAND STEEL ($MM)[7,12,13]

	1st Quarter 1978	1977	1976	1975	1974
Sales	756.5	2,681.6	2,388.2	2,107.4	2,450.3
Operating Profit	61.2	256.4	270.9	245.1	376.5
% of Sales	8.1	9.6	11.3	11.6	15.4
Pretax Profit	28.6	93.1	155.6	126.9	273.0
% of Sales	3.8	3.5	6.5	6.0	11.1
Net Income	24.2	87.8	104.0	83.3	148.0
% of Sales	3.2	3.3	4.4	4.0	6.0
Capital Expenditures	---	282.0	303.8	222.5	101.4
Raw Steel (million tonnes)	---	7.8	7.9	7.3	8.0
% of Industry	---	6.2	6.2	6.2	5.5

Pollution Control Expenditures

Table 13 gives a comparison of the amount expended by the six integrated steel companies for pollution control.

TABLE 13. POLLUTION CONTROL EXPENDITURES[12]
(all dollars in millions)

		USS	Bethlehem	National	Republic	ARMCO	Inland
Pollution Control Expenditures, 1973-1977	$	410	322	NA[a]	NA[b]	168	153
Pollution Control Expenditures, est. 1978	$	195	85	53[c]	45	16	44
Total Capital Expenditure, est. 1978	$	L.T.870[d]	500	NA	225	121	290
Raw Steel Produced, 1977 (millions tonnes)		26.2	15.1	8.5	8.4	7.2	7.1
% of Domestic Steel Production, 1977		23.1	13.3	7.5	7.4	6.2	6.2

[a] NA = not available

[b] $330 million in place 1977

[c] Total of $105 million estimated 1978 and 1979

[d] L.T. less than ($870 million is previous 5 yr. average)

6.0 WASTE CHARACTERIZATION

This study is primarily concerned with the waste materials produced by the iron and steel industry which are not likely to be hazardous subject to regulation under Subtitle C of RCRA. All wastes are identified, however, including those now proposed by EPA as hazardous (Subtitle C, Sec. 3001). The term "solid waste" means any garbage, refuse, sludge from a waste treatment plant, water supply treatment, or air pollution control facility and other discarded material, including solid, liquid, semi-solid, or contained gaseous materials resulting from industrial activities, but does not include industrial discharges which are point sources subject to permit under the Federal Water Pollution Control Act (FWPC) Section 402, as amended. Solid wastes in this industry include slag, scrap, sludge, scale, and dust. This section characterizes them in four categories: coke plant wastes, iron oxide wastes, slag, and scrap. Waste production can be related to steel production through emission factors. Flow sheets are provided to identify the source of each waste in relation to the processing operations. Wastes to air, land, and water are considered.

Waste production by state, region, and nation is given together with information on its eventual disposition.

The EPA Office of Solid Waste has proposed (40 CFR 250, 12/18/78) that certain iron and steel wastes be listed as hazardous. A discussion of the potential hazard from these wastes is reported by Enviro Control, Inc.[15] Although data are presented in this report which may be relevant to the classification of hazardous wastes, the designation of wastes for inclusion in the listings is not within the scope of this investigation. Therefore, the costs, requirements, and impact of hazardous waste disposal are not considered in this investigation. All industry waste streams not listed in the 12/18/78 proposal are considered subject to Section 4004 RCRA requirements.

Representative Iron and Steel Plant

Figure 9 shows the product movement in a "typical" 2.5 megatonne integrated iron and steel plant. The diagram shows tonnages for the various intermediate products as well as the final delivered output. It assumes that all steel is made by the BOF and EAF. The OH is omitted from this consideration because it is a declining technology.

It should be recognized, however, that the elimination of the OH from the diagram is an arbitrary constraint which is imposed on the typical plant. It is expected that certain of the open hearths in the United States are of relatively modern vintage, are equipped with environmental controls, and operate with a substantial degree of efficiency. The production of OH wastes on a state and nationwide basis is included in the solid waste listings.

Each of the individual processes, i.e, the coke oven, the blast furnace, etc. are diagramed in greater detail in subsequent process diagrams. These process diagrams are not formal material balances. They are presented to illustrate quantities of waste arising from the given throughput and are based on generation factors that may vary significantly from plant to plant. The number of significant figures used does not imply an obtainable accuracy; they are given merely as a convenience to allow closure within these installations. The diagrams show intermedia transfers of materials and are keyed to tables which show tentative materials produced and indicate the influence of compliance with present and future air and water pollution control regulations. As will be noted in greater detail in Section 6.3, the total quantity of solid waste generated in the iron and steel industry will be only slightly increased by compliance with anticipated air and water regulations.

The first step in characterization was to identify those wastes that present difficult problems for disposal. For example, coke breeze is relatively low in volume and is essentially completely recycled or reused at the present time. Coke by-product wastes are low volume but some are hazardous. Scrap, although high in tonnage, is also recycled or reused. Blast furnace slag is 90 percent recycled or reused, whereas only an estimated 45 percent of steelmaking slag is recycled. Of the iron oxide materials, the amounts which are landfilled or stockpiled are 39 percent of the dusts, 43 percent of the scales

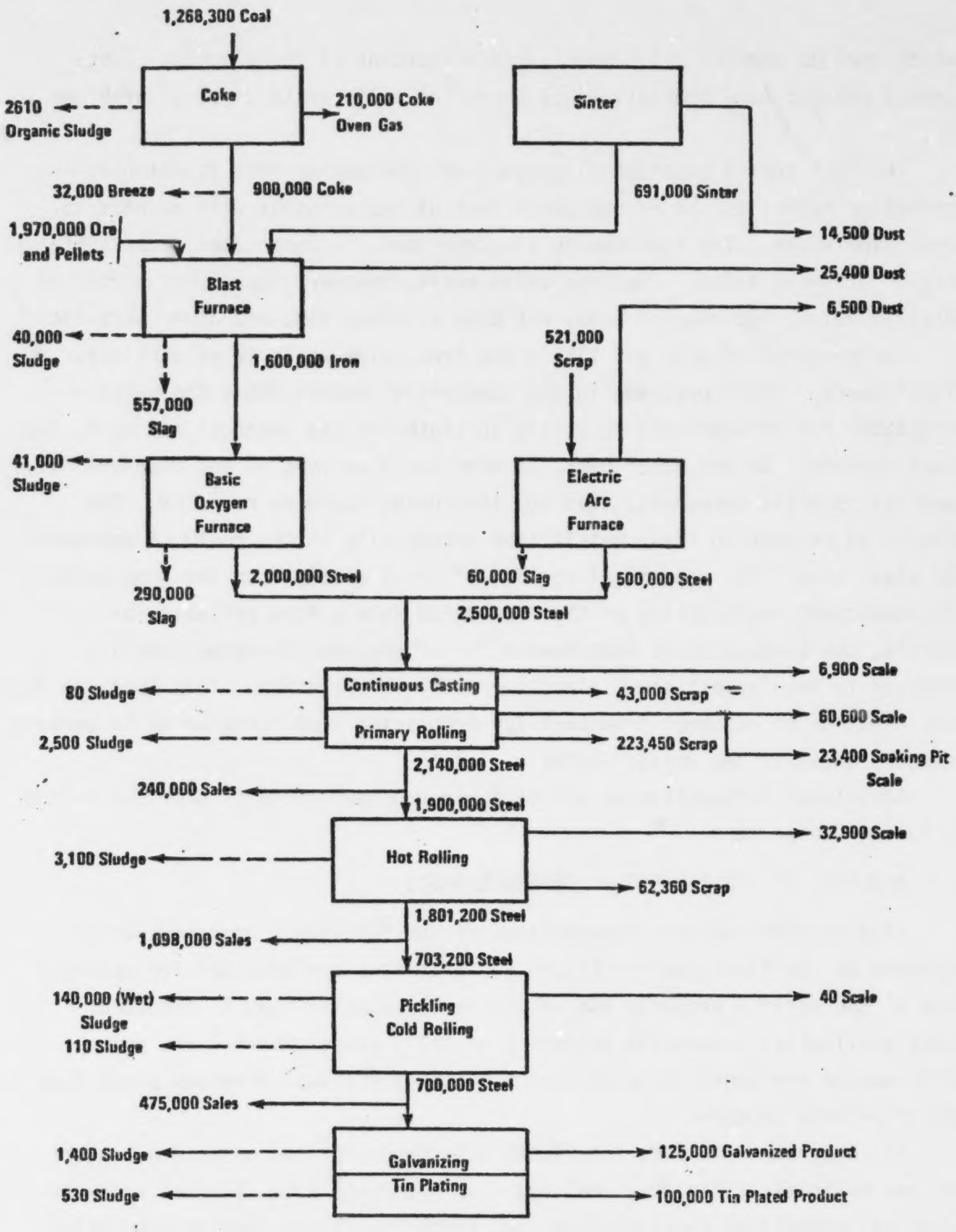


Figure 9. Waste production from typical plant with 2,500,000 tonnes of steel per year (all numbers in tonnes).

(which include soaking pit scales), and 53 percent of the sludges. These numbers present some indications of where the solid waste disposal problems lie.

The fact that a substantial portion of steelmaking slag is not used in a productive manner is not as serious a loss of resources as with respect to iron oxide waste. The steelmaking slag may have, in many cases, substantially little intrinsic value. The iron oxide waste, however, represents a loss of metallic value, not only of iron, but also of zinc, tin, and other metallics.

The presence of zinc and tin in the iron oxide waste is of particular significance. Their presence in any substantial amount makes the waste unacceptable for conventional recycling to sintering and eventual return to the blast furnace. On the other hand, if they could be removed and recovered as a separate metallic component, then the iron oxide could be recycled. The problem of recovering these metals lies essentially in the realm of economics and plant size. For economical removal of these metals from the iron oxide and subsequent reprocessing of the iron oxide into a form suitable for recycle, the process plant must handle larger amounts of wastes than are produced in the largest steel plant currently in operation. This leads to the consideration of regional treatment for processing iron oxide waste in certain selected areas of the United States.

Additional information on all of these considerations is provided in the following subsections.

6.1 ANALYSIS OF PROCESSES THAT GENERATE WASTE

This section contains descriptions of the individual processes which appeared on the flow sheet in Figure 9. Estimates are provided for material flow of the various products and of the waste material that is produced. Where applicable, intermedia transfers of solid waste material are shown. Solid wastes are shown in larger print on the individual diagrams since they are of primary concern.

An integrated steel mill performs all the operations needed to convert the raw materials (iron ore, coal and flux material) into finished products. Principal operations consist of coking, sintering, blast furnace ironmaking, steelmaking via the BOF or EAF, continuous casting, hot and cold rolling, and various finishing operations. The major operations are described in the following sections.

6.1.1 By-Product Coking

Figure 10 shows a block diagram for a typical coking operation. Of particular interest in this study is the coal charged to the coke oven, the coke which is produced, and the breeze which is a solid waste.

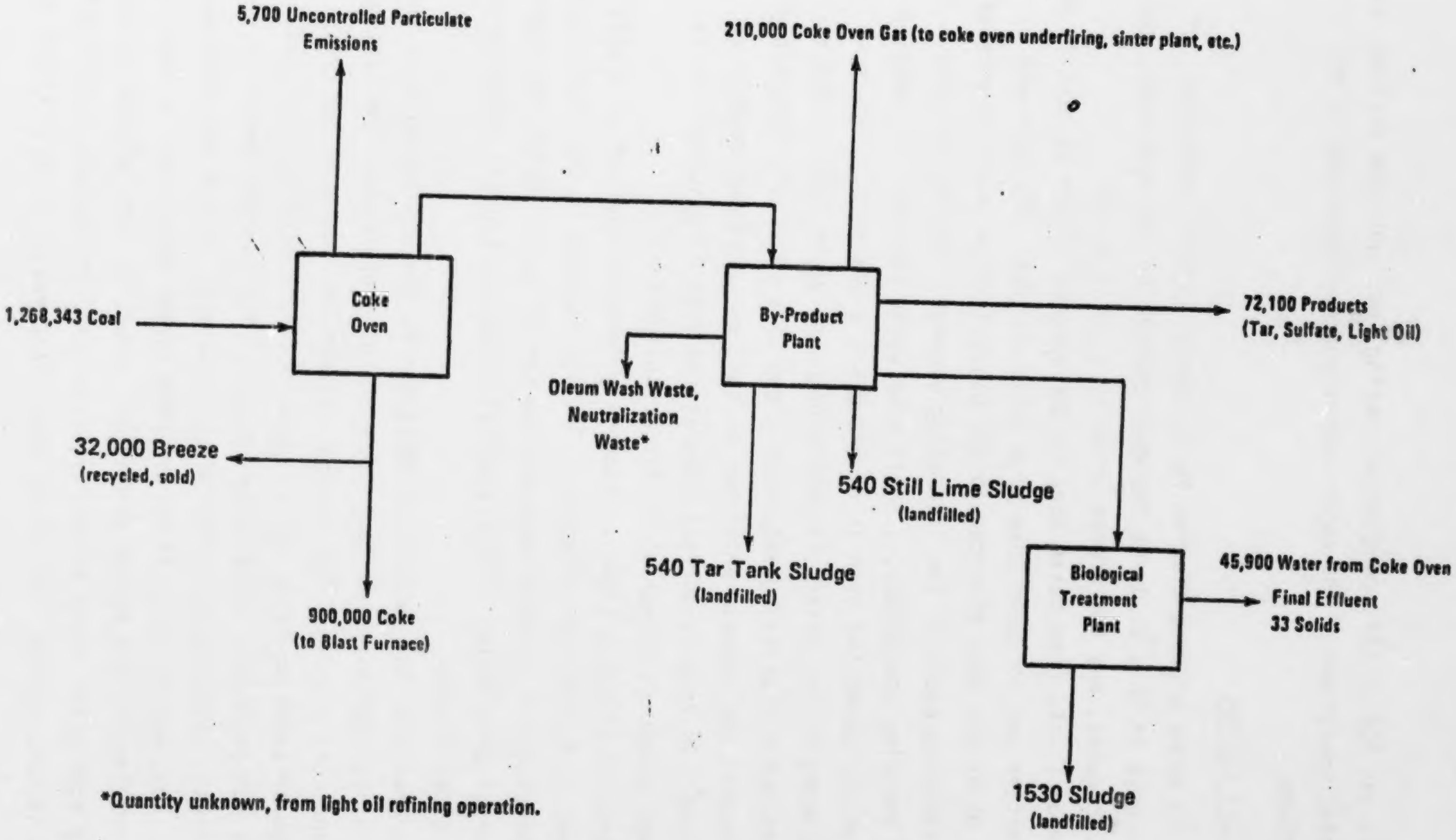
The by-product coke oven heats coal in the absence of air to distill off the volatile matter and to leave coke as a solid residue. The hot coke is quenched with water and then diverted to the blast furnace where it acts as the fuel and reducing agent in the ironmaking process. During the coke quenching and handling operations, a solid coke waste (breeze) is produced.

The gas which leaves the oven is diverted via a gas main to the by-product plant where it is cooled, thereby condensing waste liquors and tar products. Subsequent processing separates light oils which are invariably sold as by-products and ammonia which may be sold as anhydrous ammonia or ammonium sulfate. In view of current regulations regarding sulfur, it is usually removed either as elemental sulfur or sulfuric acid.

The processing of waste liquor customarily involves the use of distillation followed by biological oxidation. If lime is used in the distillation process a lime sludge is formed; however, the use of sodium hydroxide avoids the generation of this waste. The biological oxidation process normally produces a biological sludge.

Recent emphasis on the control of emissions to the atmosphere from the coking process has been directed toward the charging operation, the leakage from doors, and coke pushing. The control systems for charging and door leakage can be arranged so as to direct emissions back into the oven and, therefore, do not produce a solid waste as such. The pushing emissions control, in contrast, captures the emissions in a control device and produces a solid waste. This waste, which is mostly fine carbon particles, is small in quantity, approximately 0.5 kg per tonne (one pound per ton) of coke produced.

The only coke plant waste which may, with some confidence, be classed as nonhazardous is coke breeze. All other coke plant wastes contain either oil,


5,700 Uncontrolled Particulate Emissions
210,000 Coke Oven Gas (to coke oven underfiring, sinter plant, etc.)
1,268,343 Coal
Coke Oven
By-Product Plant
72,100 Products (Tar, Sulfate, Light Oil)
Oleum Wash Waste, Neutralization Waste*
32,000 Breeze (recycled, sold)
540 Still Lime Sludge (landfilled)
540 Tar Tank Sludge (landfilled)
Biological Treatment Plant
45,900 Water from Coke Oven
Final Effluent
33 Solids
900,000 Coke (to Blast Furnace)
1530 Sludge (landfilled)

*Quantity unknown, from light oil refining operation.

Figure 10. Material flow for coke plant in production of 2,500,000 tonnes of steel per year (all numbers in tonnes).[1]

tar, or other toxic compounds which could be classed as hazardous. In a typical integrated steel plant, all of the coke breeze is recycled or used.

In summary, the coke plant produces both potentially hazardous and nonhazardous wastes. Currently, the nonhazardous wastes are typically recycled or reused, leaving the hazardous wastes as a disposal or stockpiling problem.

6.1.2 Sintering

Figure 11 shows a material flow sheet for the sintering plant with the various charge materials indicated. Some of the sinter is used to form a hearth-layer which protects the sintering grates. The windbox exhaust is indicated as passing through a cyclone and electrostatic precipitator (ESP). Alternative control devices are scrubbers and baghouses. The discharge-end emissions are generally controlled by means of a baghouse.

The purpose of the sintering process is to agglomerate fine oxide materials into lumps necessary for charging into the blast furnace. These materials include fine ores, various recycled fine oxide waste materials from iron- and steelmaking operations, fuel (often in the form of coke breeze), and limestone for fluxing purposes. In the sintering process, the material is mixed, placed on a slowly moving grate and ignited. A downflow of air through the bed into the windbox below consumes the carbon, thereby maintaining ignition and fusing the fine materials into sinter lumps. The lumps are crushed, cooled, screened, and delivered to the blast furnace. The screening operation separates fines, but these are recycled to the sintering machine.

Dusts are generated in two general locations in the process: (1) the windbox where dusts are collected in the windbox hopper and in the final air pollution control devices, and (2) the discharge-end where dusts are generated by breaking, screening, and handling operations. Nearly all of the dust from the windbox which is collected is recycled entirely within the sintering operation. In some cases, the very fine dust which is collected by the baghouse at the discharge-end is recycled as well; in other cases it is landfilled. In any event, the quantity of this dust is comparatively small.

6.1.3 Blast Furnace Ironmaking

In the blast furnace, the various charge materials are delivered to the top of the furnace and travel slowly down to the hearth. The operation is

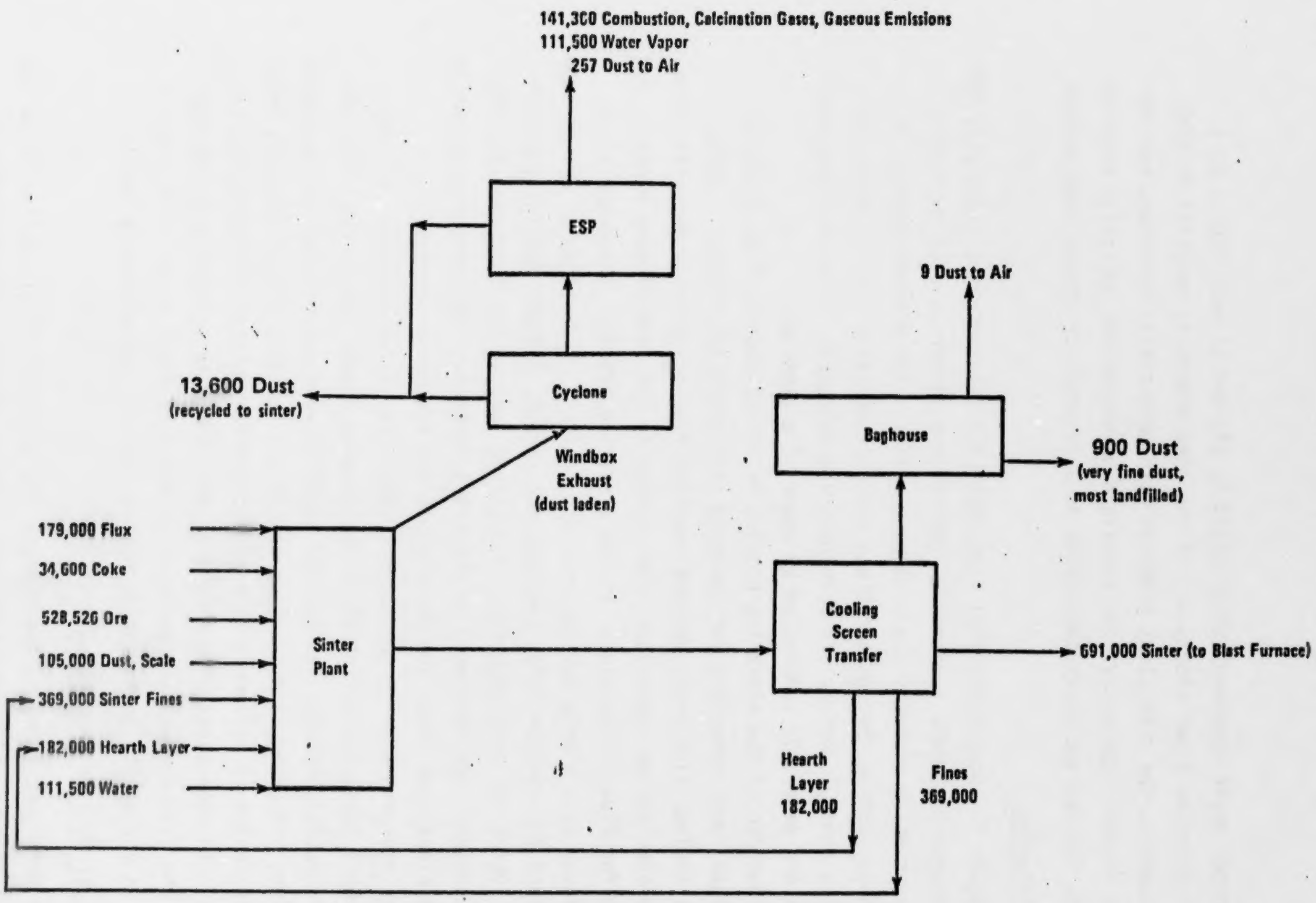


Figure 11. Material flow for sinter plant in production of 2,500,000 tonnes of steel per year (all numbers in tonnes).[17]

essentially a continuous one, but molten iron is extracted at intervals of 3 to 4 hours. The charge normally consists of coke from the coke ovens, sinter, pellets, lump ore, limestone, etc. An upward flowing current of hot air burns the carbon and creates conditions in which the iron oxide is reduced to iron, and flux is melted to remove impurities. When the furnace is tapped, the iron is removed through one set of runners and the molten slag to another.

After iron, the greatest quantity of solid from the blast furnace is slag. This material is usually crushed and processed to remove the entrained iron which is recycled to the blast furnace. As will be noted in Figure 12, approximately 90 percent of the slag is used as an aggregate concrete, road ballast, etc. The remainder is disposed of in landfill operations.

The gas leaving the top of the furnace passes through a cyclone, commonly called a dust catcher, and a high energy scrubber before it is diverted to various fuel consumers such as the blast furnace stoves which heat the hot blast, blast boilers which produce steam, etc.

Dry dust which is discharged from the dust catcher is recycled by means of the sintering process. The same is true for some of the sludge which is collected from the clarifier that serves the wet scrubbing system. However, in the case of the sludge it is sometimes not used in the sintering plant because of the somewhat greater difficulties experienced. The reasons for the difficulties lie in the finer nature of the particles and in the oil which may be contained in the sludge. This oil becomes vaporized in the sintering process, thereby causing a visible emission at the windbox end which is very difficult to capture.

Recent environmental regulations have necessitated total systems to collect particulates of iron oxides and kish which are generated during the casting of iron from the blast furnace. Kish is flakes of carbon emitted by molten iron. These emissions, which amount to about 0.3 kg/tonne of iron, are generally captured by baghouses and delivered in the form of dry dust. Most blast furnaces in the United States at this time do not capture casting emissions so that the addition of control equipment will cause an increase, although slight, in the generation of solid waste.

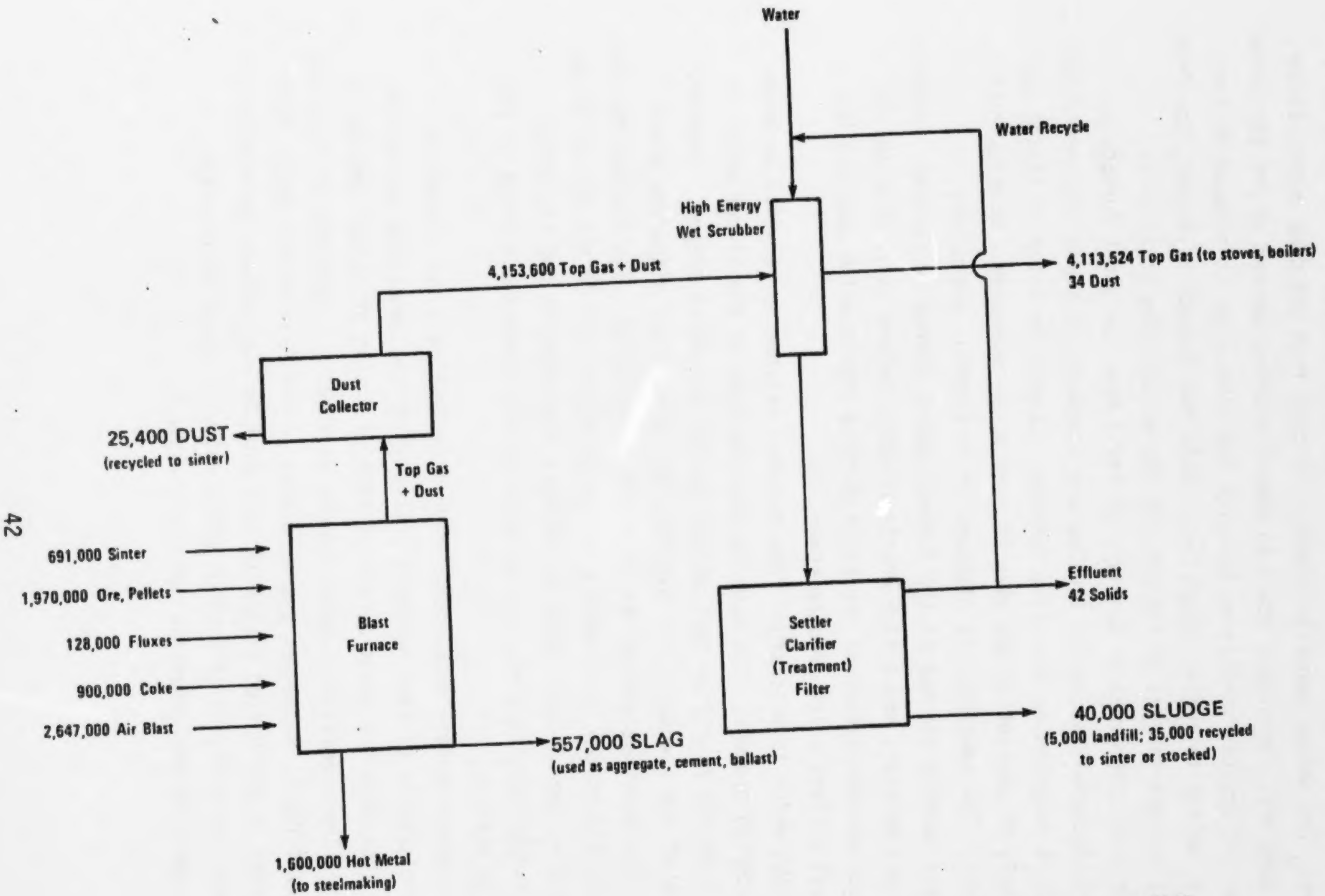


Figure 12. Blast furnace material flow in production of 2,500,000 tonnes of steel per year (all numbers in tonnes).[16,18]

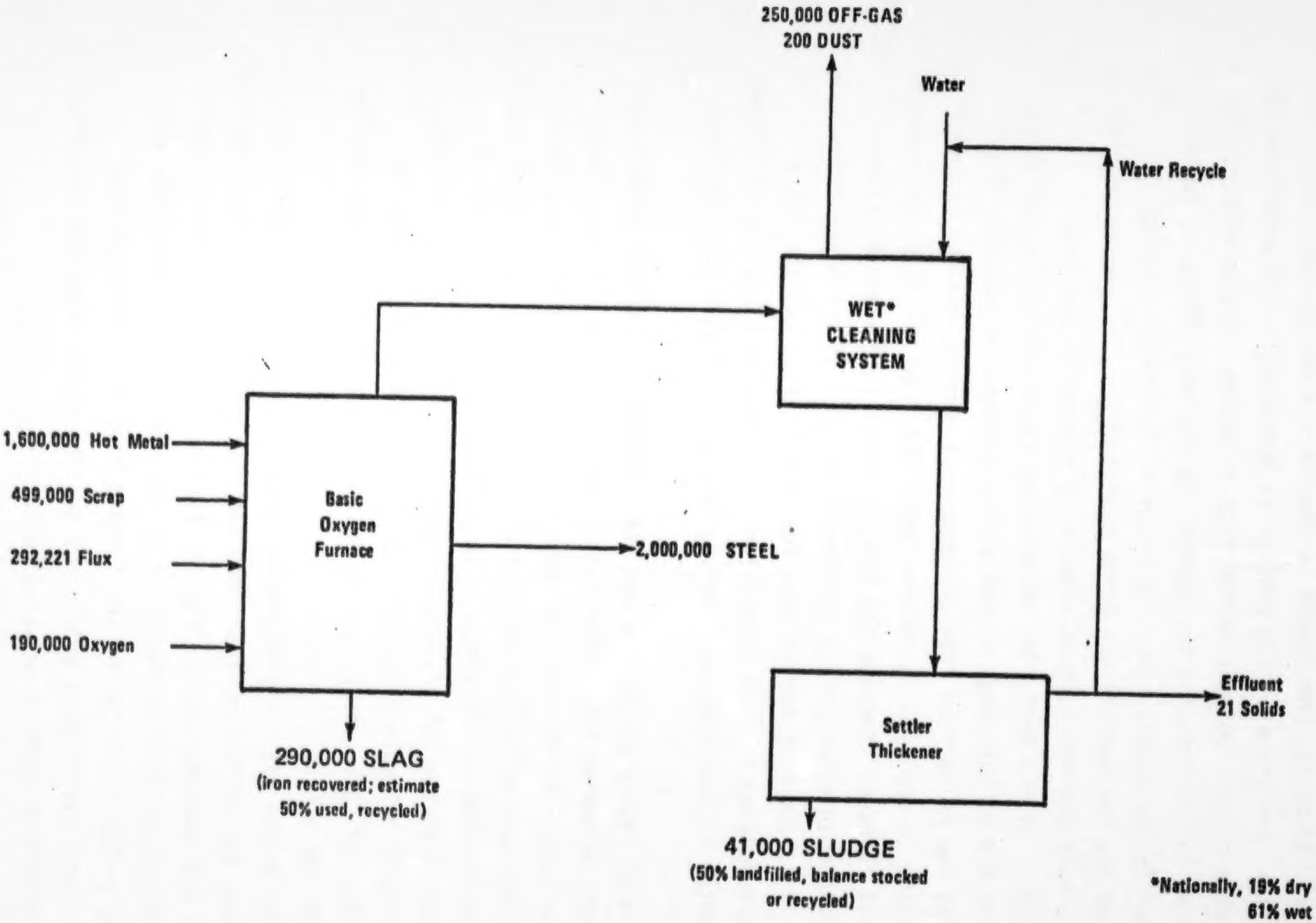
6.1.4 Basic Oxygen Steelmaking

As shown in Figure 13, the inputs to the BOF are molten iron (hot metal), scrap, flux, and oxygen. The process is essentially a chemical one in which a jet of pure oxygen impinges on the bath of molten iron to oxidize the carbon and silicon in the iron thereby generating the heat necessary to melt the scrap and purify the steel. The metallurgy of this batch process is highly controlled and the results are quite predictable. The process cycle time is called a heat and may be completed in 30 minutes to one hour.

Upon completion of the heat, the molten slag is poured into a pot which is carried to the end of the shop, dumped on the ground, and cooled. Alternatively the slag can be carried from the shop to a remote area for disposal. Magnetic separation is employed to recover metallics from the slag and recycle them to the blast furnace. Because the slag is high in lime and dissolved iron oxide, some companies recycle a portion of it back to the blast furnace. In other facilities, the slag may be used for road ballast and the like; however, most steelmaking slag is landfilled. Steelmaking slags may be wetted and aged six months to stabilize them before they are suitable for construction fill.

The diagram of Figure 13 shows a wet gas cleaning system with associated settler/thickener to remove fine oxide particulates from the offgas. These particulates are very fine in size and, depending on the type of scrap used, may contain significant quantities of zinc and lead. If so, it is usually not feasible to recycle them to the sinter plant. Therefore, the majority of steelmaking dusts from the BOF are either landfilled or stockpiled, thereby losing a potentially valuable resource. Control of BOF emissions may be achieved by a dry ESP, but the problem of solid waste disposal is essentially the same as with the wet unit.

In addition to the gas cleaning system shown in Figure 13, a BOF usually employs equipment for collecting kish from the pouring of molten iron into the shop ladle and from the shop ladle into the furnace. There is also a trend toward the provision of control equipment to capture fugitive emissions that escape from the vessel mouth during the furnace blow and during tapping. These emissions are covered in a subsequent section which relate to the effect of future air pollution control on solid waste.



*Nationally, 19% dry systems
61% wet systems
20% semi-wet systems

Figure 13. Basic oxygen process material flow in production of 2,000,000 tonnes per year of steel (all numbers in tonnes).[16]

6.1.5 Electric Arc Steelmaking

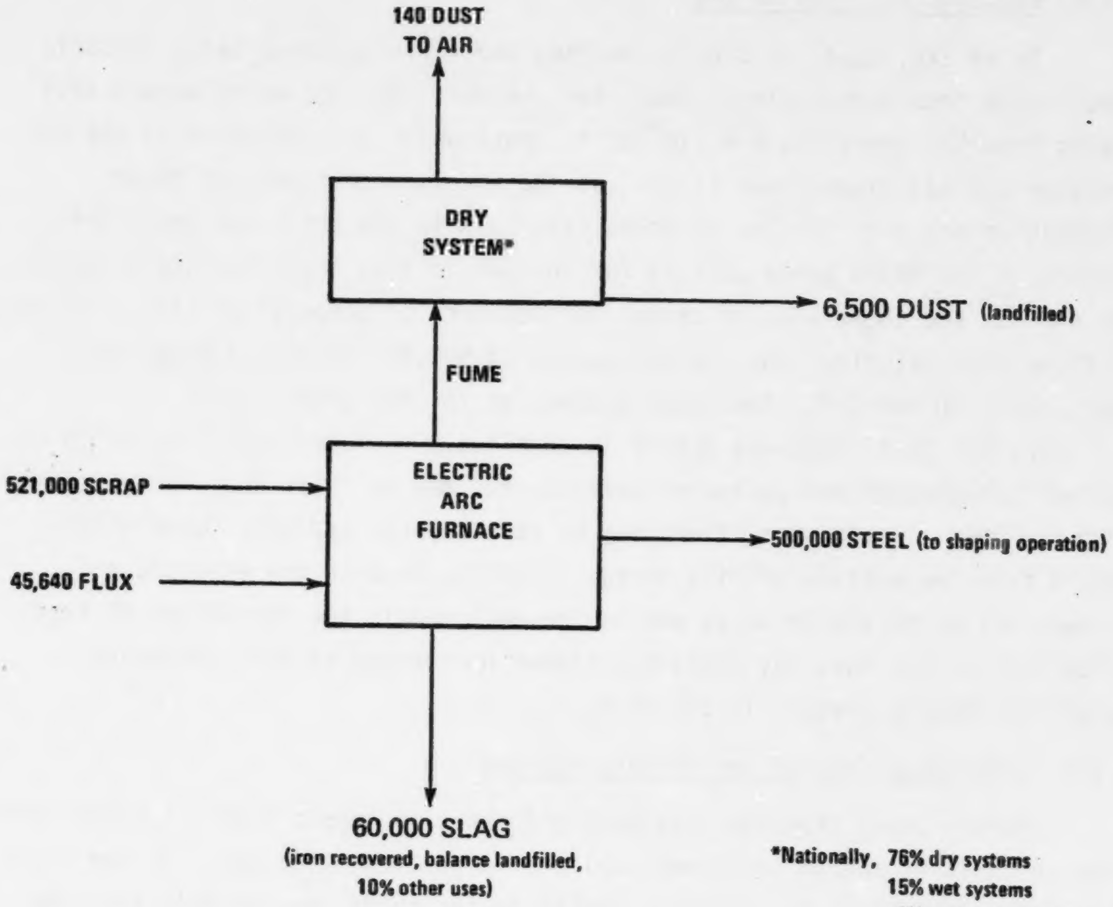
In an EAF, steel is made by melting and refining scrap using electric arcs struck from carbon electrodes. For the most part the solid wastes that result from EAF operation are similar to those which are generated by the BOF. The slag and its disposition as well as the steelmaking fumes and their disposition are very similar to those materials in the BOF. The basic difference in the solid waste picture for the EAF is that there is little use of molten iron and therefore, no system for recovery or disposal of kish. Figure 14 shows material flows for the production of 500,000 tonnes of steel per year, equal to one-fifth the total production for the model plant.

Many EAF facilities are housed in completely enclosed buildings which are vented to baghouses and collected particulates may be finer than that obtained from the BOF. In addition, there may be carbonaceous and oily fumes which result from the melting of oily scrap. Finally, because the electric arc furnace relies solely on scrap and may be employed in the production of high alloy steels, the dust may contain a higher percentage of zinc and other metallics than is present in BOF dust.

6.1.6 Continuous Casting and Primary Rolling

Molten steel from the steelmaking furnace is tapped into a teeming ladle from which it is poured into ingot molds or a continuous caster. In the ingot mold route, the steel is partially cooled in the molds, the mold is stripped from the ingot, the ingot placed in a soaking pit and reheated to rolling temperatures, and then introduced into the primary rolling mill from which the semi-finished product emerges. In the continuous caster, the steel is poured through the mold which directly forms the semi-finished shape, the latter passing through the bottom of the mold and cut into suitable lengths.

The yield of semi-finished steel is less in the ingot mold route than the continuous casting route. This loss of yield is a result of two factors. (1) The individual ingots after being rolled to the semi-finished shape contain imperfections which are rolled into the ends of the semi-finished shape. These ends must be cropped and scrapped. (2) There is a loss of steel from oxide formation in the soaking pit. This loss in yield in conjunction with the energy required to fuel the soaking pit furnace, results in increased cost of



*Nationally, 76% dry systems
15% wet systems
9% semi-wet systems

Figure 14. Electric arc furnace material flow in production of 500,000 tonnes of steel per year (all numbers in tonnes).[16]

production as compared to the continuously cast semi-finished steel. In consequence, continuous casting is gradually replacing the ingot mold-primary rolling mill route of making semi-finished steel.

Both processes of converting molten steel into semi-finished steel result in a generation of mill scale and scrap. The generation of these wastes is much larger in the ingot route than in the continuous casting route. However, in each case the wastes are essentially 100 percent recycled or stocked for future use.

The ingot method of making semi-finished steel results in an additional solid waste in the soaking pit, called soaking pit scale or slag. This waste, largely because of the refractory content, is landfilled. There are also small amounts of iron oxide sludge which are produced and these are generally landfilled. All of these situations are diagramed on Figure 15.

6.1.7 Hot and Cold Rolling

The process of converting semi-finished steel into a finished product involves heating it in a reheat furnace followed by hot rolling to the desired physical shape. In the case of structural shapes, the finished product is most often taken from the hot mill, cut to specific size and sold. In the case of strip and sheet, the hot roll product is sometimes sold; however, it is often pickled, a process to remove scale by immersion in a bath of sulfuric or hydrochloric acid and then cold rolled to achieve the desired characteristics of gauge tolerance, surface finish, and metallurgy.

Figure 16 shows a typical sequence for producing steel from the finishing mills. Steel, entering from the left of the diagram, passes through the hot rolling process. A portion of it is sold directly from this process. Another portion, approximately 39 percent is pickled, rinsed to remove the acid solutions and cold rolled. Of the cold rolled products, approximately 68 percent is sold directly from the mill and the remainder passes on to galvanizing, tinning, and other coating processes.

The hot rolling finishing mills produce the same type of solid waste as is produced in the primary mill. These wastes are scraps, mill scale, and sludge. The difference between the waste products of the two types of mills is that solid waste from the finishing mills are finer and smaller in quantity than those from the primary mills. The disposal of wastes from both mills is essentially the same.

There are two wastes which are produced by the pickling process, namely waste pickle liquor and pickle rinse water. Both are acidic and contain dissolved metallic compounds, principally iron. If sulfuric acid pickling is used the metallic salt is ferrous sulfate; if hydrochloric acid is used it is ferrous chloride. Either one, upon neutralization produces a sludge which has little value, is typically impounded in lagoons, and is very difficult to

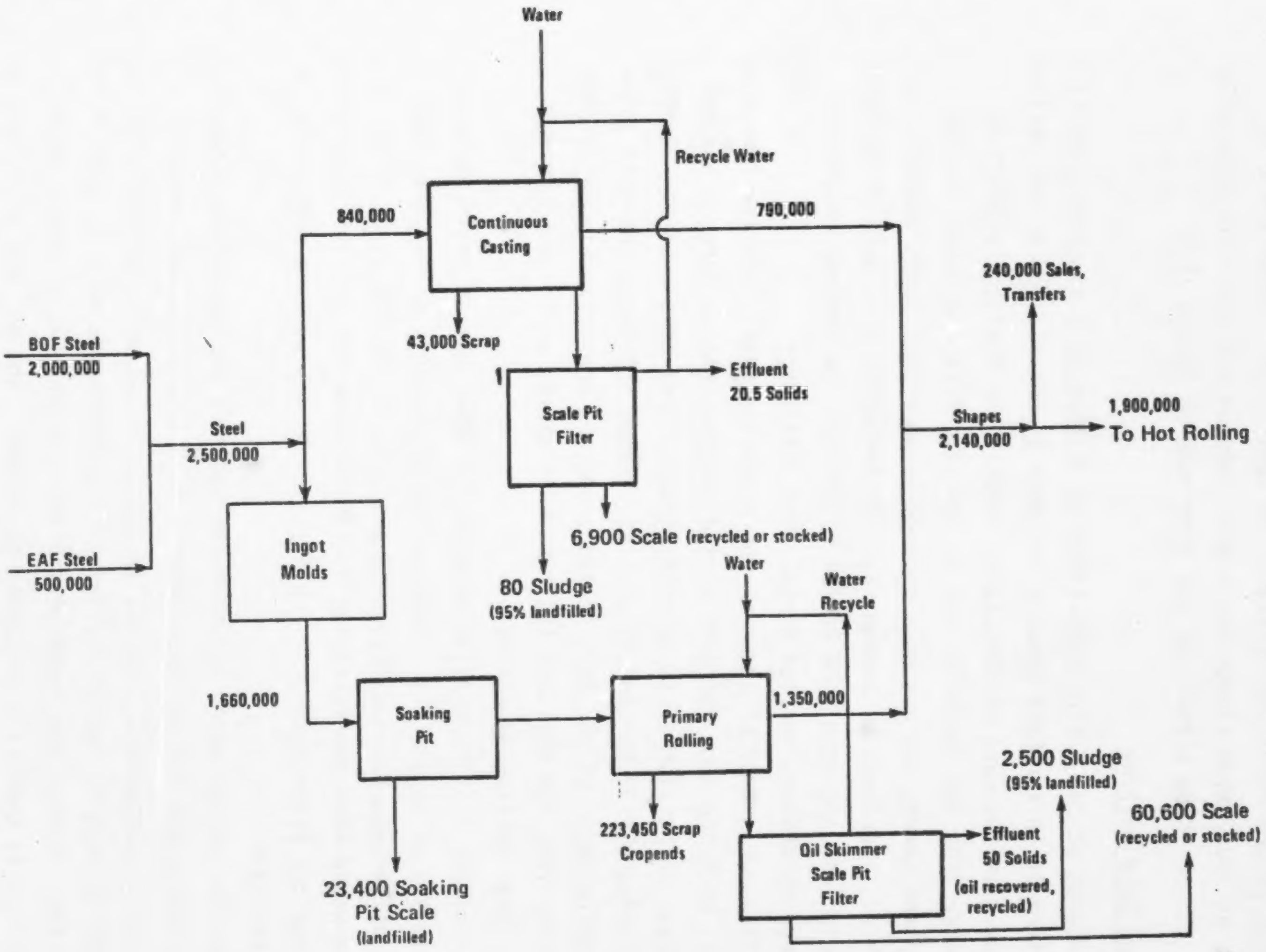


Figure 15. Continuous casting, soaking, primary rolling material flow in production of 2,500,000 tonnes of steel per year (all numbers in tonnes).[16]

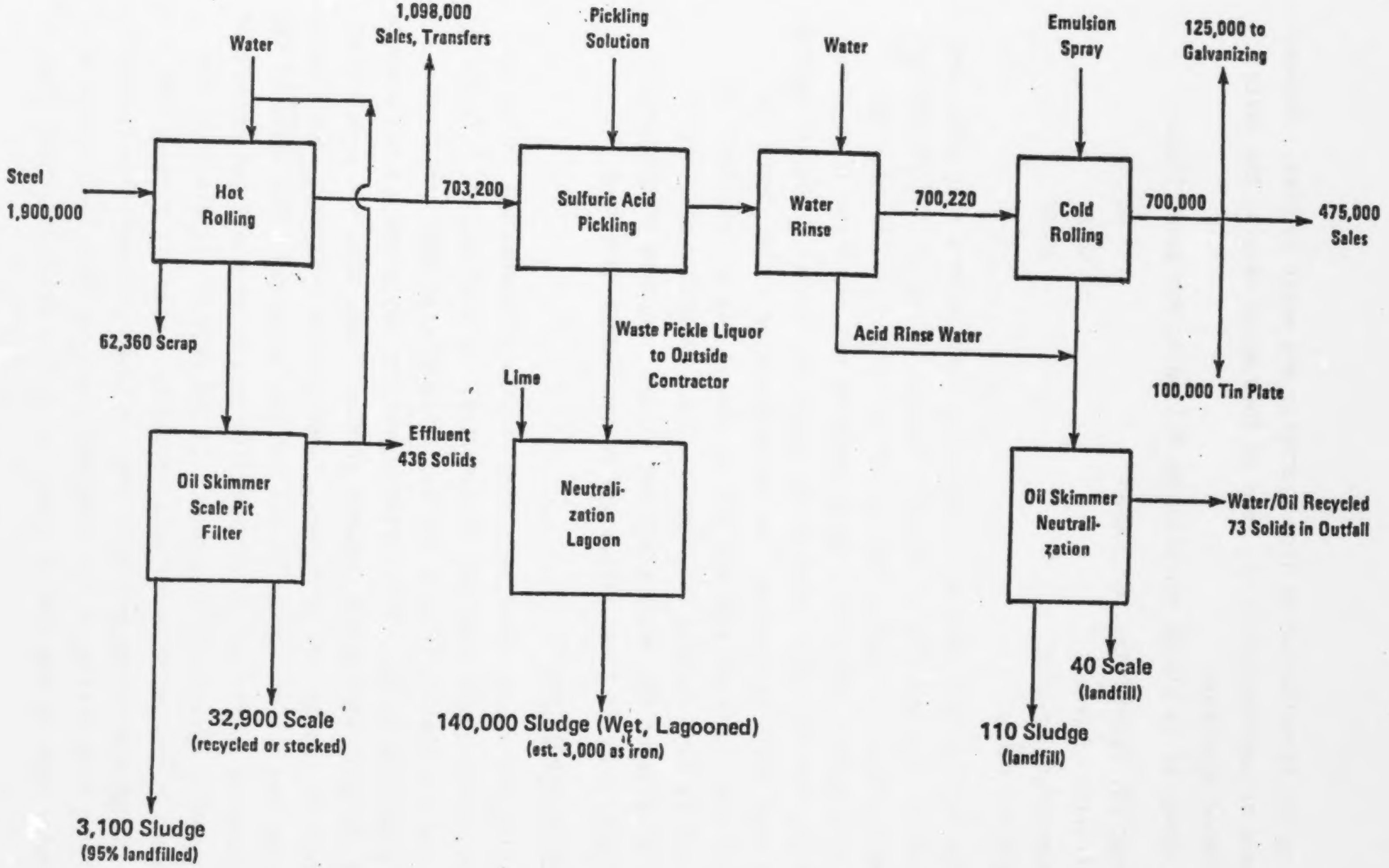


Figure 16. Hot and cold rolling in the production of an overall total of 2,500,000 tonnes of steel per year (all numbers in tonnes).[16]

dewater due to the formation of an iron hydroxide and water complex. Because of the presence of various metallics, some of them heavy metals, the waste may be considered hazardous.

An EPA survey of 16 plants revealed the following for spent liquor:

Recycled, regenerated, or reused	7.4%
Untreated disposal	60.8%
Neutralized on-site	20.5%
Contract hauler	11.3%

Untreated disposal includes deep-well injection, dumping on a slag pile, and direct discharge. The quantity of sludge shown in Figure 16 (140,000 tonnes) is the wet weight based on neutralizing spent sulfuric acid pickle liquor.[19]

In the cold rolling operation, an emulsion of oil and water is used to cool the rollers and the steel sheet as it is rolled thinner. The oil becomes contaminated with scale and sludge. In the more modern mills, there are internal facilities for purifying the oil so that it may be recycled. In others, the oil is sent outside for reprocessing. In either case, it is necessary to dispose of the waste scale and sludge. Because of the substantial oil content, some of these wastes may be considered hazardous.

6.1.8 Finishing Operations

Finishing operations comprise a wide variety of operations including metal forming, cutting and shearing, galvanizing, tin plating, etc. Electrogalvanizing and tin plating (Figure 17) may produce scrap metal which is recycled or otherwise reused. The latter operations may produce a solid waste sludge which contains significant amounts of zinc, lead, tin, etc., depending upon the nature of the process involved. These sludges originate from electroplating methods and are not formed in the hot dip technique. The value of the metallic content is sufficient to economically justify recovery and recycle of the metals, usually by an outside vendor. In the case of tin plating, even the rinse water is sent outside for metal recovery. (The tin plating and galvanizing sludge quantities are small and are based on generation factors for sludge resulting from residuals from cleaning lines and from neutralization of acid rinse water used in the plating operation at the water treatment plant.)[16]

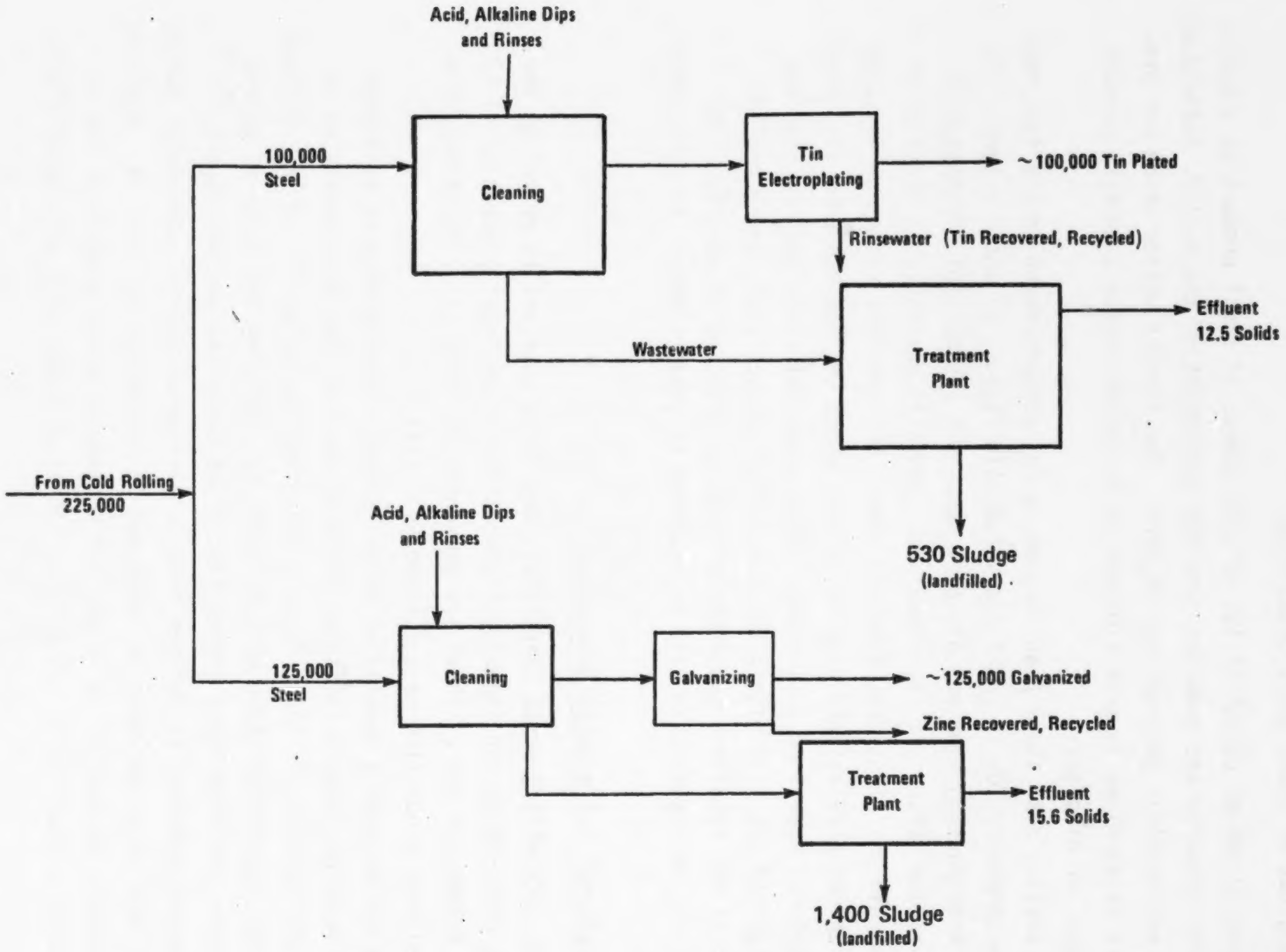


Figure 17. Tin plating, galvanizing material flow for 2,500,000 tonnes of steel per year (all numbers in tonnes).[16]

6.2 MAGNITUDE OF SOLID WASTE GENERATION

Using an annual output of 125 million tonnes of steel product as a basis, the wastes produced are examined from the standpoint of the nation, individual states, and specific geographical regions. The various wastes which are produced are categorized in such a manner as to reflect their alternate present use, reuse, or disposal.

In dealing with steel plant wastes, a key consideration is the fact that they are generally low in intrinsic value with respect to their weight. The cost of transporting them any distance becomes a substantial percentage of their ultimate value. It is, therefore, generally desirable to recycle the wastes within the plant that produces them. One possible exception is scrap iron which has a relatively high value and, under certain economic situations, may be shipped over long distances. Other waste materials such as slag and iron oxide, if not used within the plant that produce them, are normally consumed in the immediate geographical area or disposed of on-site. The implications of these facts will be examined in greater detail in subsequent sections.

6.2.1 National Solid Waste Generation

In determining waste quantities, the first step was to establish the tonnages produced by the individual processes for an ingot production of 125 million tonnes per year. These are presented in Table 14. The values were developed from production data for the year 1977.

The corresponding quantities of solid wastes generated were estimated using generation factors (emission factors) derived from data presented by Dravo[20] and Calspan.[16] These factors are given in Tables 15 and 16. Minimum and maximum quantities shown were obtained by examining the range of generation factors for individual plants listed the Dravo and Calspan report.[16,20] The estimated quantity is derived from an average or typical generation factor that was felt to be the most reliable and is referenced in Table 15. Applying the generation factors of Table 15, the nationwide waste quantities for an annual total production of 125 million tonnes of steel were calculated (Table 16).

TABLE 14. INDIVIDUAL PROCESS OUTPUTS FOR PRODUCTION OF 125,000,000 TONNES OF STEEL PER YEAR* (ALL NUMBERS IN TONNES)

BOF	77,400,000
OH Steel	19,700,000
EAF Steel	27,900,000
Total Steel Production	125,000,000
Coke	48,500,000
Sinter	35,100,000
Blast Furnace	81,300,000
Continuous Casting	15,300,000
Soaking	87,200,000
Primary Rolling	87,200,000
Hot Rolling	84,800,000
Cold Rolling	34,400,000
Galvanizing	5,300,000
Tin Mill	6,400,000

*Based on 1977 production.[9]

Table 17 summarizes the annual generation of solid wastes for 125 million ingot tonnes of production into four categories: (1) coke plant wastes, (2) slag, (3) iron oxide wastes (including dusts), and (4) scrap.

As noted in the table, both coke breeze and metallic scrap are essentially recycled or reused in a useful manner. From the standpoint of disposal, these two items are taken care of, in most cases, by present practices, and for this reason need no further consideration. Slag and iron oxide wastes are not fully utilized and will be covered in greater detail.

6.2.2 Slags

There are two types of slag wastes, ironmaking and steelmaking. Table 18 shows the various components which make up a typical ironmaking slag and a range of basic oxygen furnace steelmaking slags. There is a wide variation in the range of compositions for the basic oxygen furnace slags. The nature of the slag varies depending upon the metallurgy of the process involved, upon the impurities in the feed materials to the process, principally sulfur, and upon the end product.

TABLE 15. WASTE GENERATION FACTORS AND QUANTITIES FOR A TYPICAL 2,500,000 TONNE YEAR/PLANT[16,1,20]

Waste	Quantity of Waste, tonnes/yr Minimum	RTI Estimate	Maximum	Generation Factor (tonne/tonne) of product	Reference[a]	Reference Product
Coke Breeze	17,300	32,400	45,000	0.036	(1)	Coke
Still Lime Sludge	315	540	540	0.000604	(2)	Coke
Tar Sludge	90	540	540	0.0006	(3)	Coke
Coke Treatment Plant Sludge	---	1,530	1,710	0.0017	(3)	Coke
Blast Furnace Slag	345,600	556,800	820,800	0.348	(2)	Iron[c]
Blast Furnace Dust	11,200	25,360	54,500	0.01585	(1),(2)	Iron
Blast Furnace Sludge	3,200	40,000	44,800	0.025	(2),(4)	Iron
Blast Furnace Dust and Sludge	25,600	65,460	72,000	0.04085	(1),(2),(4)	Iron
EAF Slag	25,000	60,000	164,500	0.120	(2)	EAF Steel
EAF Dust	2,925	6,500	8,000	0.013	(1)	EAF Steel
BOF Slag	230,000	290,000	400,000	0.145	(2)	BOF Steel
BOF Dust, Sludge	16,000	41,000	60,000	0.0205[b]	(4)	BOF Steel
Sinter Fines	---	369,000	---	0.527	(3)	Sinter
Sinter Dust	6,910	14,511	44,224	0.021	(1)	Sinter
Continuous Casting Scale	158	6,900	19,750	0.0087	(2)	C.C. Steel
Continuous Casting Sludge	---	80	---	0.000104	(2)	C.C. Steel
Soaking Pit Scale	---	23,400	54,900	0.015	(3)	S.P. Steel
Primary Mill Scale	---	60,600	---	0.0449	(2)	P.M. Steel
Primary Mill Sludge	---	2,500	---	0.00187	(2)	P.M. Steel
Hot Rolling Scale	---	32,900	---	0.0183	(2)	H.R.M. Steel
Hot Rolling Sludge	---	3,100	---	0.00174	(2)	H.R.M. Steel

TABLE 15. (cont'd)

Waste	Quantity of Waste, tonnes/yr Minimum	RTI Estimate	Maximum	Generation Factor (tonne/tonne) of product	Reference[a]	Reference Product
Cold Rolling Scale	---	40	---	0.000052	(2)	C.R.M. Steel
Cold Rolling Sludge	338	110	---	0.00016	(2)	C.R.M. Steel
Galvanizing Sludge	---	1,350	---	0.0108	(2)	Finishing Steel
Tin Plating Sludge	---	530	---	0.00532	(2)	Finishing Steel
Bricks, Rubble	---	250,000	---	0.1	(5)	Total Steel
TOTALS	684,636	1,885,151	1,791,264			

[a] (1) Dravo Corporation, 1976
(2) Calspan Corporation, 1977
(3) RTI Estimate
(4) Datagraphics, 1976
(5) AISI

[b] Factor applies separately to dust and sludge.

[c] Also agrees with the ratio of national slag to iron production.

TABLE 16. NATIONWIDE WASTE GENERATION FOR 125,000,000 TONNES OF STEEL PER YEAR (WASTE QUANTITIES IN THOUSANDS OF TONNES PER YEAR)

Waste	Generated	Disposition[a]		
		Landfilled	Stocked	Recycled, Reused
Coke Breeze	1,750	0	0	1,750
Ammonia Still Lime Sludge	30	30	0	0
Tar Sludge	30	30	0	0
Coke Treatment Plant Sludge	80	80	0	0
Blast Furnace Slag	28,300	2,800	0	25,500
Blast Furnace Dust	1,290	170	120	1,000
Blast Furnace Sludge	2,030	270	190	1,570
EAF Slag	3,350	2,550	0	800
EAF Dust[b]	290	280	0	10
EAF Sludge	70	67	0	3
Open Hearth Slag	4,790	2,400	0	2,400
Open Hearth Dust	270	160	70	40
BOF Slag	11,220	5,600	0	5,600
BOF Dust[b]	490	250	120	120
BOF Sludge	1,100	550	286	264
Sinter Fines	18,500	0	0	18,500
Sinter Dust	740	40	0	700
Continuous Casting Scale	130	0	40	90
Continuous Casting Sludge	1.6	1.1	0	0.5
Soaking Pit Scale	1,310	1,310	0	0
Primary Mill Scale	3,920	0	1,180	2,740
Primary Mill Sludge	160	150	0	10
Hot Rolling Scale	1,550	0	450	1,100
Hot Rolling Sludge	150	140	0	10
Cold Rolling Scale	2	2	0	0
Cold Rolling Sludge	6	6	0	0
Pickle Liquor Sludge	350[c]	350	0	0
Galvanizing Sludge	60	60	0	0
Tin Plating Sludge	30	23	0	7
Scrap Metal	42,300	0	0	42,300
Bricks and Rubble	12,500	12,500	0	0
Fly and Bottom Ash[d]	380	380	0	0
TOTALS	137,179.6	30,199.1	2,456	104,514.5

[a] Disposition is based on estimates by Calspan,[16] Dravo,[20] and RTI.

[b] EAF and BOF dust/sludge distribution based on number of wet and dry collection systems used.[4]

[c] Value, 350, derived from Dravo estimate of 400 for 1974.[20]

[d] Based on coal usage for production of steam.[9]

TABLE 17. SUMMARY OF WASTE GENERATION FOR 125,000,000 TONNES OF STEEL PER YEAR (THOUSANDS OF TONNES PER YEAR)[a]

Waste	Generated	Landfilled	%	Stocked	%	Recycled or Used	%
COKE PLANT							
Coke Breeze	1,750	---		---		1,750	100
Ammonia Still Lime Sludge	30	30	100				
Tar Sludge	30	30	100				
Water Treatment Plant Sludge	80	80	100				
Total	1,890	140	7			1,750	93
SLAG							
Ironmaking	28,300	2,800	10	---		25,500	90
Steelmaking	19,360	10,560	55	---		8,800	45
Total	47,660	13,360	28	---		34,300	72
IRON OXIDE							
Dust:							
Sinter	740	40	6	---		700	94
Ironmaking	1,290	170	13	120	9	1,000	78
Steelmaking	1,050	690	66	190	18	170	16
Total	3,080	900	29	310	10	1,870	61
Sludge:							
Ironmaking	2,030	270	13	190	9	1,570	78
Steelmaking	1,170	617	53	286	24	267	23
Mill	758	730	96	---		28	4
Total	3,958	1,617	41	476	12	1,865	47

TABLE 17. (cont'd)

Waste	Generated	Landfilled	%	Stocked	%	Recycled or Used	%
Scale:							
Soaking Pit	1,310	1,310	100	---		---	
Mill	5,602	2		1,670	30	3,930	70
Total	6,912	1,312	19	1,670	24	3,930	57
Total Iron Oxide	13,950	3,829	27	2,456	18	7,665	55
SCRAP							
Metallic Scrap	42,300	---		---		42,300	100
Rubble, Brick	12,500	12,500	100				
Total	54,800	12,500	23			42,300	77
GRAND TOTAL	118,300	29,829	25	2,456	2	86,015	73

[a] Disposition is based on estimates by Calspan[16], Dravo[20], and RTI.

TABLE 18. IRON AND STEELMAKING SLAGS

	COMPOSITIONS - %		
	Ironmaking Slag[18]	Basic Oxygen Furnace Slag	
Slag Component	Average	Allegheny-Lud.[a]	Wheeling-Pitt.[b]
FeO	---	20.7-26.4	15-30
SiO_2	35.3	20.4-22.9	9-13
Al_2O_3	12.8	0.7-1.2	0.1-0.3
CaO	41.2	39-40.8	32-42
MgO	8.3	9-10.2	5-10
MnO	---	2.7-3.6	4-8
Cr_2O_3	---	0.4-0.6	---
P_2O_5	---	0.3-0.6	---
S	1.4	0.03-0.04	0.1-0.3
Other	1.0	---	---
Slag ratio (basicity)[c]	1.03	2.1-2.3	3.3-3.9

[a] Based on two analyses, Pennsylvania Department of Environmental Resources

[b] General ranges, Pennsylvania Department of Environmental Resources

[c] Slag ratio = $(\%CaO + \%MgO) \div (\%SiO_2 + \%Al_2O_3)$

Steelmaking slag differs from ironmaking slag in two essential respects. The steelmaking slag contains significant quantities of iron oxide whereas ironmaking slag contains less than 1 percent iron oxide. Also, the slag ratio, or basicity, of steelmaking slag is considerably higher than ironmaking slag. These two facts are important in relationship to the end use of the slag. Because ironmaking slag is less basic, it is more useful for construction purposes such as road building, railroad ballast, and concrete aggregate. In contrast, the steelmaking slag is not readily adapted to those purposes. However, the iron content of steelmaking slag and its high basicity make it useful for recycle as a charge material for the blast furnace. The chemical composition of the two slags thus substantially affect their end use and disposal.

The slag data in Table 17 indicates that 90 percent of ironmaking slag is recycled and 10 percent is landfilled. It would not be unreasonable to assume that the landfilling operation, in large part, was carried out deliberately to provide additional space in the steelmaking operations rather than as a necessity to get rid of unwanted materials. For example, filling operations are going on at one steel company on the shore of Lake Michigan and at another on the Chesapeake Bay. In contrast, only 45 percent of the steelmaking slag is reused whereas 55 percent is landfilled. Because steelmaking slag has high basicity and is rather limey, care must be taken when placing it in the ground that the disposal site is at a distance from a receiving body of water. If such care is not taken, it is possible that a heavy rain may leach lime from the slag and create an effluent which is high in pH.

6.2.3 Iron Oxide Solid Waste

In the steel industry the apparently nonhazardous solid wastes which create the greatest disposal problem are iron oxide wastes. The production and disposal of iron oxide waste is summarized in Table 17 in the categories of dust, sludge, and scale. Within each category there are subcategories which define the source of the waste as, for example in the case of dust, sinter, ironmaking, and steelmaking. Each of these categories and subcategories describe an iron oxide waste which is distinctive from the standpoint of composition, particle size, moisture content, and contaminants. Each presents its own problems, or lack of them, in respect to the potential for recycle or reuse.

Tables 19, 20, 21, and 22 present chemical analysis of the blast furnace dust, blast furnace sludge, BOF sand, and BOF fines respectively. An examination of these tables reveals a number of pertinent facts, as follows:

1. A particular solid waste, for example blast furnace dust, is quite variable from facility to facility and even within the facility itself. In the case of this dust, the iron content varies from 5.9 to 54.0 percent, a spread of almost one order of magnitude.
2. In a given process, the larger particles may have a substantially different composition than the finer particles. For example, in the BOF under Plant E, the sands have an iron content of about 33 percent whereas the fines have a iron content of about 44 percent. The contrast is even

TABLE 19. CHEMICAL ANALYSIS OF BLAST-FURNACE DUSTS

(percent by weight)

Reference	ID		Fe	C	S	Pb	Sn	Zn	Mn	Na_2O	K_2O	Al_2O_3	CaO	MgO	SiO_2	As	Sb	Se
20	C	Low	31.4	28.5	0.14	0.01	0.01	0.07	0.06	0.07	2.3	2.0	4.2	2.2				
20		High	38.2	32.4	0.28	0.01	0.04	0.09	0.15	0.10	4.5	5.4	5.4	3.0	7.6	< 0.02	< 0.01	< 0.01[a]
20	E	Low	29.0	34.4	0.36	0.02	< 0.01	0.05	0.11	0.04	1.6	1.7	2.4	1.1				
20		High	31.3	36.1	0.39	0.03	0.03	0.12	0.16	0.05	2.6	1.7	3.0	1.2	5.2	< 0.02	< 0.01	< 0.01
20	F	Low	49.4	17.3	0.33	0.06	0.04	0.17	0.04	0.04	0.4	1.1	1.8	2.4				
20		High	54.0	20.3	0.42	0.08	0.04	0.21	0.04	0.09	1.2	1.5	6.0	3.1	5.4	0.02	0.01	0.01 [sic]
20	H	Low	25.8	44.8	0.16	0.02	< 0.01	0.01	0.04	0.08	1.0	0.8	2.7	0.6				
20		High	35.6	50.7	0.34	0.03	0.02	0.03	0.08	0.13	1.6	6.1	5.4	1.8	5.4	< 0.02	< 0.01	< 0.01
20	I	Low	16.8	28.7	0.10	0.01	0.04	0.01	0.42	0.07	0.02	1.7	7.1	1.9				
20		High	20.8	43.7	0.75	0.01	0.04	0.02	1.52	0.11	0.8	2.5	8.7	2.5	11.1	< 0.02	< 0.01	< 0.01
20	L	Low	20.4	20.0	0.23	0.05	< 0.01	0.02	0.15	0.15	1.8	2.4	3.7	2.1				
20		High	46.8	53.6	0.66	0.15	0.04	0.02	0.20	0.33	3.0	7.6	11.0	2.6	7.2	< 0.02	< 0.01	< 0.01
22		Low	36	3.5	0.2	n.d.[b]	n.d.	n.d.	0.5	n.d.	n.d.	2	3.8	0.2	8			
22		High	50	15	0.4	n.d.	n.d.	n.d.	1.0	n.d.	n.d.	15	28	5	30			
21	MW		47.1	n.d.	n.d.	n.d.	n.d.	0.5	0.7	0.2	1.0	1.9	4.1	0.2	8.2			
21	US	Low	36.5	3.7	0.2	n.d.	n.d.	n.d.	0.5	n.d.	n.d.	2.2	3.8	0.9	8.9			
21		High	50.3	13.9	0.4	n.d.	n.d.	n.d.	0.9	n.d.	n.d.	5.3	4.5	1.6	13.4			
23	Primary	Low	20.0	6.6	n.d.	0.001	n.d.	0.08	n.d.	0.095	0.48	n.d.	n.d.	n.d.	n.d.			
23		High	49.9	50.0	n.d.	0.28	n.d.	2.7	n.d.	0.52	1.82	n.d.	n.d.	n.d.	n.d.			
23	Secondary	Low	5.9	11.2	n.d.	0.05	n.d.	0.08	n.d.	0.04	0.30	n.d.	n.d.	n.d.	n.d.			
23		High	43	33.9	n.d.	3.4	n.d.	11.5	n.d.	1.4	5.4	n.d.	n.d.	n.d.	n.d.			
24			32.2	28.5	0.2	n.d.	n.d.	0.45	0.5	n.d.	n.d.	2.5	3.1	0.7	6.9			
25			27.0	21.4	n.d.	0.01	n.d.	0.05	1.1	n.d.	n.d.	1.2	5.2	2.2	7.3			
26			23.6	41.1	0.2	0.01	n.d.	0.08										
27	O.K.	Low	31.5	10.0	0.2	0.2	n.d.	0.7	0.4	n.d.	0.5	2.6	6.0	1.0	9.8			
27		High	51.0	30.0	0.7	0.3	n.d.	0.8	1.0	n.d.	1.5	6.5	7.0	2.0	11.0			
28	Germ.		50.0	11.0	0.2	0.1	n.d.	0.8	n.d.	0.3	0.2	n.d.	4.5	0.9	6.8			
29	U.S.		29.0	25.4	0.54	< 0.05	n.d.	0.15	0.34	6.4	n.d.	13.2	9.4	0.07	11.6			
30	O.K.		43	2.5	3.4	0.02	0.01	0.4	n.d.	n.d.	n.d.	3.8	n.d.	n.d.	n.d.	0.001		
31	O.K.		39.2	20.56	0.35	0.015	< 0.01	0.08	1.41	0.32	0.77	1.37	5.38	1.93	7.28			

[a] SiO_2, As, Sb, and Se shown for only one sample.

[b] Not determined.

TABLE 20. COMPOSITION OF BLAST-FURNACE SLUDGE, PERCENT BY WEIGHT (DRY BASIS)

Reference	ID		Fe	C	S	Pb	Sn	Zn	Mn	Na_2O	K_2O	Al_2O_3	CaO	MgO	SiO_2	As	Sb	Se
20	C	Low	25.6	27.7	0.19	0.09	<0.01	0.50	0.06	0.05	1.1	3.6	4.4	2.4	9.3^a	$<0.02^a$	$<0.01^a$	$<0.01^a$
20		High	29.4	29.8	0.47	0.13	0.01	1.11	0.14	0.08	1.9	4.7	3.0					
20	D		21.8	40.9	0.25	0.10	0.06	1.6	0.07	0.11	1.9	2.6	3.2	1.8	9.7	<0.02	<0.01	<0.01
20	E	Low	40.7	21.1	0.46	0.13	0.02	0.26	0.10	0.04	0.9	2.1	2.8	0.9	6.2^a	$<0.02^a$	$<0.01^a$	$<0.01^a$
20		High	43.0	24.3	0.46	0.19	0.03	0.38	0.17	0.04	1.2	3.1	3.2	1.2				
20	F	Low	38.9	18.3	0.78	0.09	0.04	2.1	0.01	0.08	0.6	0.3	3.5	2.2	6.5^a	$<0.02^a$	$<0.01^a$	$<0.01^a$
20		High	39.6	18.9	0.94	1.02	0.05	2.6	0.02	0.09	0.9	0.3	4.0	2.3				
20	I	Low	24.7	30.2	0.25	0.04	0.02	0.04	0.10	0.03	0.4	1.7	4.0	1.5	7.8^a	$<0.02^a$	$<0.01^a$	$<0.01^a$
20		High	30.2	40.5	0.68	0.05	0.03	0.07	0.29	0.04	0.6	2.2	5.6	2.0				
20	M	Low	27.5	20.9	0.63	0.05	0.01	0.08	0.06	0.03	0.6	1.8	4.7	1.2	7.5^a	$<0.02^a$	$<0.01^a$	$<0.01^a$
20		High	35.6	35.1	1.01	0.07	0.03	0.14	0.17	0.08	1.2	2.3	8.2	1.9				
20	Japanese		45	5.5	4.6	0.03	0.01	0.2	b	–	–	6.2	7.7	–	–	0.007		
24	Japanese		28.6	40.8	0.3	–	–	0.5	0.3	–	–	3.0	2.7	0.7	6.1			
	German		27.5	17.8	2.0	4.2	n.d.	9.5										
32		Low	40.2	1.1	0.08	–	–	0.2	–	–	–	2.1	3.1	0.9	4.1			
32		High	61.0	16.0	0.3	–	–	0.3	–	–	–	3.9	4.6	5.9	8.5			
27	UK		33.6	23.3	–	0.3	–	0.7	0.4	–	0.5	2.8	7.5	1.1	10.5			
21	USA	c	42.9	15.6^h	0.4	–	–	0^g	0.49	0.2	0.6	4.4	3.6	1.7				
		d	10.1	–	1.9	–	–	1.2	1.67	9.2	20.9	6.9	6.4	8.0				
		e	13.5	16.0^h	1.3	–	–	0.9	0.85	1.6	2.7	15.6	7.1	9.9				
		f	6.0	–	1.4	–	–	1.2	1.15	9.8	22.4	6.7	4.7	9.3				

[a] Determined for only one sample.

[b] Blanks mean not determined or not reported.

[c] Sludge from washers.

[d] Dust in gas leaving washers.

[e] Sludge from wet precipitator.

[f] Dust in gas leaving precipitator.

[g] Not detected by standard methods.

[h] Loss on ignition.

TABLE 21. CHEMICAL ANALYSES OF BOF RESIDUES–SANDS[20]

(weight %–dry)

Plant	Sample	Fe	C	S	Pb	Sn	Zn	Mn	Na_2O	K_2O	Al_2O_3	CaO	MgO	SiO_2	As	Sb	Se
A[b]	Filter cake[a]																
	1	59.1	0.9	0.02	0.02	0.10	0.01	0.61	0.03	0.03	0.13	15.9	2.0	3.4	<0.02	<0.01	<0.01
	2	50.6	1.8	0.04	0.21	0.10	0.01	0.52	0.11	0.18	0.38	11.4	1.8				
E[c]	Sludge[b]																
	1	35.0	1.0	0.06	0.01	0.02	0.3	0.67	0.03	0.14	0.62	23.7	2.1	13.0	<0.02	<0.01	<0.01
	2	32.4	2.0	0.08	0.02	0.04	3.3	0.72	0.03	0.16	0.53	20.8	1.6				
I	Sludge[d]																
	1	52.9	1.6	0.10	<0.01	0.02	0.01	0.32	0.04	0.08	0.25	16.1	8.3	2.8	<0.02	<0.01	<0.01
	2	46.1	1.1	0.09	0.01	0.02	0.01	0.28	0.03	0.07	0.21	15.2	4.8				
	3	47.3	1.0	0.06	<0.01	0.01	0.01	0.36	0.03	0.05	0.25	15.4	5,7				
	4	55.5	0.9	0.02	<0.01	0.01	0.01	0.88	0.01	0.05	0.25	13.8	3.6				
J	Sludge[d]																
	1	53.7	0.6	<0.01	<0.01	<0.01	0.03	0.16	0.01	0.01	0.15	5.4	1.7	3.7	<0.02	<0.02	<0.01
	2	66.4	0.4	<0.01	<0.01	0.01	0.05	0.25	<0.01	0.01	0.08	2.8	0.79				
	3	61.6	0.7	0.01	0.01	<0.01	0.05	0.47	0.01	0.01	0.13	5.4	1.8				
	4	59.3	0.5	0.01	0.01	0.01	0.08	0.33	0.01	0.01	0.15	9.2	2.1				

[a] Rake classifier and scrubber fines combined.

[b] Settling basin.

[c] Q-BOP

[d] Rake classifier.

TABLE 22. CHEMICAL ANALYSES OF BOF RESIDUES–FINES[20]

(weight %–dry)

Plant	Sample	Fe	C	S	Pb	Sn	Zn	Mn	Na_2O	K_2O	Al_2O_3	CaO	MgO	SiO_2	As	Sb	Se
E[a]	Sludge[b]																
	1	45.2	2.9	0.18	0.13	0.02	12.8	0.58	0.07	0.27	0.30	5.6	0.66	1.8	<0.02	<0.01	<0.01
	2	43.9	3.1	0.44	0.09	0.04	13.7	0.55	0.05	0.23	0.25	5.9	0.60				
F	Dust[c]																
	1	58.3	0.7	0.04	0.05	0.02	0.24	0.12	0.27	1.2	0.09	7.6	0.61	2.8	<0.02	<0.01	<0.01
	2	60.4	0.5	0.01	0.04	0.03	0.12	0.13	0.35	0.70	0.08	6.0	0.61				
G	Sludge[b]																
	1	60.2	1.4	0.20	1.8	0.06	2.0	0.50	0.11	0.31	0.08	3.6	0.98	1.6	<0.02	<0.01	<0.01
	2	60.7	1.5	0.17	1.7	0.04	1.7	0.52	0.07	0.29	0.09	4.2	0.99				
	3	61.9	1.3	0.15	1.6	0.04	1.6	0.41	0.07	0.22	0.11	3.4	0.80				
	4	61.8	1.2	0.13	1.4	<0.01	1.4	0.37	0.07	0.27	0.08	3.6	0.75				
I	Sludge[b]																
	1	55.6	1.7	0.14	0.04	<0.01	0.07	0.36	0.11	0.12	0.11	6.9	2.0	2.3	<0.02	<0.01	<0.01
	2	56.5	1.4	0.13	0.07	<0.01	0.07	0.50	0.09	0.12	0.08	6.1	2.4				
	3	57.4	1.3	0.13	0.06	<0.01	0.09	0.59	0.11	0.12	0.08	5.7	2.0				
	4	55.6	1.6	0.11	0.05	<0.01	0.07	0.34	0.09	0.12	0.09	6.5	2.6				
K	Sludge[b]																
	1	53.4	1.5	0.10	0.73	0.05	4.5	0.12	0.18	0.35	0.17	6.0	1.1	2.0	<0.02	<0.01	<0.01
	2	61.2	1.5	0.10	0.60	0.02	3.5	0.08	0.13	0.47	0.55	8.9	1.2				
	3	57.5	1.1	0.07	0.29	0.01	1.4	0.14	0.11	0.27	0.17	6.4	1.4				
	4	56.2	2.6	0.15	0.60	0.02	3.7	0.35	0.13	0.37	0.25	4.6	1.0				

[a] Q-BOP.

[b] Scrubber.

[c] ESP.

more marked in respect to zinc content in which the sands have a zinc content of 2 percent and the fines a zinc content of about 13 percent.

Physical characteristics of the wastes are almost as important as chemical compositions. The fine particulate sludges are much more difficult to recycle than the coarse dry dusts. If oil is present in any substantial quantity along with the sludge, difficulties are imposed on the sintering process.

Table 17 indicates that, of the total iron oxide in all categories, 55 percent is recycled or reused and 45 percent is landfilled or stocked. In this connection, the word "stocked" should be used with some discretion. In some steelmaking facilities, where iron oxide is said to be stocked for a future use, this indeed represents a true fact. In other plants the same terminology may be used as euphemism when disposal is the actual intent.

If steelmaking dusts and sludges are considered by themselves, of a total generation amounting to 2.2 million tonnes per year, 80 percent is either landfilled or stocked and only 20 percent is reused. Many problems are associated with recycling these wastes. A few of the key ones are as follows:

1. Zinc and lead in the dust are carried into the sinter and from there to the blast furnace, where it interferes with flue operations of the blast furnace and causes premature destruction of the furnace lining.
2. The very fine particulates cause handling problems and interfere with smooth operations of the sintering process.
3. The iron content of steelmaking fines is usually small although often highly variable.
4. The tonnage of waste iron oxide generated in a single steelmaking facility is too small to economically support a sophisticated and technically correct process for recovering the waste and converting it to a useful form. For this reason, there have been investigations into the regional concept of treating these wastes, bearing in mind that their relatively low intrinsic value is an impediment to transporting them any distance. Thus, any regional concept can serve only a limited geographical area. This concept is discussed further in Section 6.2.5.

6.2.4 Solid Waste Generation by State

Table 23 provides information on the distribution of iron and steelmaking capacity by state. In preparing the Table, the capacity values reported to EPA by each plant in the United States were summed to obtain a total of 158 million tonnes.[4] This total was then adjusted to the AISI industry estimate of 143 million tonnes (158 million tons).

In recent years production has been less than capacity and, therefore, Table 24 shows the waste that would be generated in each state if the national production were 125 million tonnes per year. This provides a numerical reference point that, in any given year of the current decade, is close to actual production.

This production was then multiplied by the generation factors of Table 15 to obtain the waste generations shown in Table 24. Examination of the Table indicates that the first five states listed, Pennsylvania, Indiana, Ohio, Illinois, and Michigan account for over 70 percent of the total solid waste produced.

6.2.5 Solid Waste Generation by Geographical Region

There are six geographical regions in the United States in which the density of iron and steelmaking facilities is high. These regions, in their order of density, are Chicago, Pittsburgh, Cleveland, Philadelphia, Youngstown, and Birmingham. Table 25 analyzes the generation of slag, iron oxide waste, and organic sludge for each of the geographical regions based on an annual national production of 125 million tonnes. The data on slag and organic sludge is presented for general information. The data on iron oxide waste is of more significance because it provides the basis for regional plants specifically designed to process them.

Table 26 shows the quantities of iron oxide wastes available for treatment in a regional plant. These quantities are now landfilled or stockpiled. They were determined by subtracting the quantities recycled from the quantities generated (Table 25). Percentage recycle for sludge is 47; for dust, 61; and for scale, 57.

Table 27 indicates some of the economic considerations which go into the evaluation of the regional treatment concept. It assumes that commercial

TABLE 23. ESTIMATED STATE DISTRIBUTION OF IRON AND STEEL CAPACITY (THOUSANDS OF TONNES)[3,4]

			STEELMAKING CAPACITY			
State	No. of Plants	Blast Furnace	Basic Oxygen	Electric Arc	Open Hearth	Total Steel
Pennsylvania	44	21,392	14,428	6,647	7,992	29,067
Indiana	7	18,493	21,004	925	1,910	23,839
Ohio	19	16,105	14,812	3,993	4,970	23,775
Illinois	15	8,343	9,603	4,483	0	14,086
Michigan	6	8,118	9,466	1,905	0	11,371
Maryland	3	5,559	2,867	136	2,831	5,834
Texas	12	993	0	4,181	1,003	5,184
New York	9	3,681	4,031	497	273	4,801
Alabama	6	3,345	3,735	346	0	4,081
West Virginia	2	2,313	3,656	275	0	3,931
California	9	2,102	1,200	753	1,794	3.747
Kentucky	4	1,635	2,086	647	0	2,733
Utah	1	1,664	0	0	2,093	2,093
Colorado	1	1,257	1,430	300	0	1,730
Missouri	1	0	0	889	0	889
South Carolina	3	0	0	745	0	745
Washington	3	0	0	717	0	717
Georgia	2	0	0	616	0	616
Florida	3	0	0	582	0	582
Delaware	1	0	0	434	0	434
New Jersey	2	0	0	376	0	376
Tennessee	2	0	0	330	0	330
Oklahoma	1	0	0	312	0	312
Oregon	1	0	0	234	0	234
Connecticut	1	0	0	208	0	208
Nebraska	1	0	0	208	0	208
Mississippi	1	0	0	186	0	186
Minnesota	1	0	0	156	0	156
Iowa	1	0	0	150	0	150
Arizona	1	0	0	130	0	130
Arkansas	1	0	0	121	0	121
North Carolina	1	0	0	120	0	120
Rhode Island	1	0	0	55	0	55
Hawaii	1	0	0	52	0	52
Virginia	1	0	0	52	0	52
Wisconsin	1	0	0	52	0	52
TOTAL	169	95,000	88,318	31,813	22,866	143,000

TABLE 24. ESTIMATED STATE DISTRIBUTION OF WASTES GENERATED FROM 125,000,000 TONNES STEEL PRODUCTION (ALL NUMBERS IN THOUSANDS OF TONNES)

State	Slag	Sludge	Dust	Scale
Pennsylvania	10,404	839	694	1,510
Indiana	8,554	827	556	1,151
Ohio	8,056	687	452	1,184
Illinois	4,124	383	273	679
Michigan	3,768	354	207	505
Maryland	2,605	201	231	312
New York	1,695	66	91	232
Texas	1,540	57	80	244
Alabama	1,484	152	111	192
California	1,228	88	82	195
West Virginia	1,164	125	92	148
Utah	933	49	61	122
Kentucky	809	79	51	136
Colorado	580	55	39	88
Missouri	95	4	8	39
South Carolina	79	2.8	7	20
Washington	76	3.5	6.8	42
Georgia	65	3.1	5.8	28
Florida	62	1.9	5.5	11
Delaware	47	1.7	4.1	11
New Jersey	40	1.6	3.5	14
Tennessee	36	1.4	3.1	13
Oklahoma	34	1.1	2.9	7
Oregon	25	1.1	2.2	14
Connecticut	22	1.0	2.0	12
Nebraska	22	0.8	2.0	4
Mississippi	20	0.7	1.7	4
Minnesota	17	2.0	1.5	9
Iowa	16	0.5	1.4	3
Arizona	14	0.6	1.2	8
Arkansas	13	0.4	1.1	7
North Carolina	13	0.4	1.0	2
Hawaii	6	0.3	0.5	3
Rhode Island	6	0.3	0.5	3
Virginia	6	0.3	0.5	3
Wisconsin	6	0.3	0.5	3
TOTAL	47,664	3,990	3,083	6,958

TABLE 25. WASTE GENERATION BY GEOGRAPHICAL REGION

Region	No. of Plants	Center	Maximum Miles To Center	Slag	Iron Oxide Sludge	Iron Oxide Dust	Scale	Organic Sludge
				(thousands of tonnes)				
Chicago (includes Northern Indiana)	15	South Chicago	30	11,774	996	748	1,467	28
Pittsburgh (includes Weirton, WV, and Steubenville, OH)	27	Pittsburgh	40	8,709	673	312	1,166	41
Cleveland (includes Lorain, OH)	4	Cleveland	22	3,102	265	153	415	8
Philadelphia (includes Bethlehem, PA)	5	Fairless Hills	60	2,747	173	187	356	7
Youngstown, OH (includes Warren, OH)	5	Youngstown	10	1,824	114	122	309	4
Birmingham, AL (includes Gadsden, AL)	6	Birmingham	55	1,503	132	111	192	11

TABLE 26. IRON OXIDE WASTES AVAILABLE FOR REGIONAL TREATMENT (NOT PRESENTLY RECYCLED)

Geographical Region	Recovery Plant Location	Available Iron Oxide Quantities (thousands of tonnes per year)			
		Sludge	Dust	Scale	Total
Chicago	South Chicago	528[a]	292[b]	631[c]	1,451
Pittsburgh	Pittsburgh	357	200	501	1,058
Cleveland	Cleveland	140	60	178	378
Philadelphia	Fairless Hills	92	73	153	318
Youngstown	Youngstown	60	48	133	241
Birmingham	Birmingham	70	43	83	196

[a] Based on 47% recycle of generated sludge.

[b] Based on 61% recycle of generated dust.

[c] Based on 57% recycle of generated scale.

TABLE 27. ORDER OF MAGNITUDE ESTIMATE OF REGIONAL PLANT ECONOMICS

		Per Tonne of Waste
1.	Pellets produced at $25/tonne iron content; (assumes 56% iron content of waste)	$ 14.00
2.	Zinc recovered at $204/tonne;[16] (assumes 6% zinc content and 90% recovery)	11.02
3.	Landfill Charge	1.50
	TOTAL $ GENERATED	$ 26.52
4.	Minus Production Cost[16] (for 350,000 dry TPY of waste)	- 23.32
5.	Gross Value	$ 3.20

6. If the waste transportation cost is $0.06/tonne-mile,[16] at the break even value the waste can be transported 53 miles ($3.20 ÷ 0.06) from the source to the treatment plant.

quality pellets will be produced from iron oxide dust at $25 per tonne of iron content and that zinc will be recovered at $204 per tonne. If the iron pellets are prereduced in the process, the value will increase. The landfill charge of $1.50 per tonne is the assumed present cost of disposing of the iron oxide. As noted, the production costs for the plant, excluding transportation, were obtained from data provided by Calspan.[16] The calculation indicates a potential gross value of $3.20 per tonne of waste. This would allow, at break even value, the waste to be transported 53 miles from the source of generation to the treatment plant. No transportation costs are provided for the finished product because it is assumed that the treatment plant would be located adjacent to the ironmaking facility where the product could be used.

The data in Tables 26 and 27 must be used with care. They represent a first order of magnitude approximation to the economics of the process. Some factors which may upset the calculations are given below:

1. The percent usage factor in Table 26 is an average for the entire industry. The particular percent usage will vary from plant to plant and from one geographical region to another.
2. The value of the pellets will vary depending upon whether or not they are prereduced.
3. The production costs, including capital, will vary from area to area depending upon labor rates, fuel costs, etc.
4. The production costs will vary from region to region depending upon the size of processing plant. The larger the production throughput of the plant, the smaller will be the unit cost.
5. Within a region, the cost of transporting the waste from the originating plant to the process plant will depend not only on the distance, but also upon the available method of transport, whether trucks, railroads, etc.

In spite of the uncertainties in the economics as listed above, the rough calculation indicates that the concept of a regional plant for processing iron oxide waste may have value in certain specific locations in the United States.

6.3 SOLID WASTE PROJECTIONS

The information in the preceding sections covered the present conditions in the iron and steel industry in regard to the generation and disposition of nonhazardous solid waste. This section provides a projection of the growth that may be anticipated in the future. The projections are based on the expected impact on solid waste generations, of air and water pollution control regulations, and expected changes in steel production.

6.3.1 Effect of Air Regulations

In order to determine the maximum possible effect that implementation of air pollution control may have on the generation of solid waste, calculations were made on the assumption of 100 percent future control. This degree of control is not likely to be achievable but its use provides an estimate of the maximum amount of solid waste that may be produced by the imposition of new regulations.

Table 28 presents calculations on present particulate pollution for five processes, namely coke plant, sinter plant, blast furnaces, BOF, and electric arc furnaces. Present air pollutant loads would become additional solid waste under future control. Not included in these calculations is the consideration of fugitive emissions from storage piles, road traffic, etc. It is recognized that these fugitive emissions may be comparatively large in quantity; however, the type of control envisioned would not generate solid waste. Such control would include elimination of emissions at the source, equipment modifications, sweeping and wetting down of roadways, watering of storage piles, etc. Such controls would tend to retain the dust at its source of generation, rather than transferring it to a solid waste disposal problem.

The five processes were chosen as those that would contribute the most to solid waste generation through additional air pollution control. This is a simplification in that removal of non-particulates may also generate some additional solid waste in water treatment facilities. However, non-particulate removal is not expected to contribute a significant quantity relative to the assumed 100 percent control of the five processes shown.

Table 29 presents a summary of additional solid wastes which would be generated by the entire industry under future more stringent air regulations. It is assumed that the waste from the coke plant being essentially carbon wastes, could be recycled within the confines of the producing plant. The iron oxide wastes would be very fine and quite difficult to treat; however, the tonnage is very small in comparison to the tonnage of solid waste that is

TABLE 28. ESTIMATED DUST GENERATION TO AIR UNDER PRESENT CONTROLS

1.	Coke Plant	48,500,000 tonnes/yr[1]
	Emission Factor:	1.0 kg/tonne pushing[1] 2.0 kg/tonne quenching[1]
	Dust Emitted:	145,500 tonnes/yr
2.	Sinter Plant	35,100,000 tonnes/yr
	Emission Factor:	0.16 kg/tonne of feed[a]
	Dust Emitted:	11,870 tonnes/yr
3.	Blast Furnace	81,300,000 tonnes/yr
	Emission Factor:	11 mg/scm from flue gas[33] 0.3 kg/tonne from cast house
	Dust Emitted:	26,117 tonnes/yr
4.	Basic Oxygen Furnace	77,400,000 tonnes/yr
	Emission Factor:	0.1 kg/tonne from offgas[b] 0.48 kg/tonne from tapping, charging, metal transfer[35]
	Dust Emitted:	44,890 tonnes/yr
5.	Electric Arc Furnace	27,900,000 tonnes/yr
	Emission Factor:	0.28 kg/tonne[c]
	Dust Emitted:	8,590 tonnes/yr

[a] 8 of 9 plants in EPA survey had emissions less than 0.16 kg/tonne feed.

[b] Worst case in EPA survey of 5 plants.

[c] Worst case in EPA survey of 6 plants.

TABLE 29. IMPACT OF FUTURE AIR REGULATIONS ON SOLID WASTE

	Additional Quantities of Solid Waste (tonnes/year)[a]	
Process	Carbon Wastes (tonnes/yr)	Iron Oxide Wastes (tonnes/yr)
Coke Plant	145,500	---
Sinter Plant	---	11,870
Blast Furnace	---	26,117
Basic Oxygen Furnace	---	44,890
Electric Arc Furnace	---	8,590
TOTALS	145,500[b]	91,467
Present Process Waste Landfilled	17,189,000[c]	
% Increase	0.5[d]	

[a] Estimate is for national total production rate of 125,000,000 tonnes of steel per year.

[b] It is anticipated that coke plant wastes will be recycled.

[c] Landfilled waste excluding rubble and brick.

[d] Assumes strictest possible regulations, that is, zero emissions.

presently being landfilled. The impact of future air regulations on process waste is an increase of 0.5 percent.

6.3.2 Effect of Water Regulations

Table 30 provides an analysis of the generation of solid waste which results from compliance with future water pollution control regulations for the iron and steel industry. Two simplifying assumptions were made in computing the data in the Table. The first is to assume that the industry presently generates solid waste derived from wastewater treatment equivalent to the 1977 water pollution control regulations. Even though the effluent quality for some plants still does not comply with these regulations, other effluents in compliance exceed them in other respects. Therefore, for the purpose of estimating sludge generation, this first assumption is reasonably close to the current situation. A check with the EPA Permits Division in November 1978 revealed that only 20 plants are not meeting the 1977 regulations and are on a timetable for compliance.[36] The second simplifying assumption is that the ultimate control imposed upon the steel industry will generate no more solid waste than from the 1983 regulations. If control requirements extend beyond these regulations, for example to include the concept of "zero discharge," there will be a substantial increase in the tonnage of solid waste, greater than indicated by the Table.

Table 30 indicates that the imposition of future water pollution control measures will create 29,700 tonnes annually from suspended solids. Assuming that these are not recycled, they will add approximately 0.2 percent to the process wastes which are presently landfilled.

6.3.3 Effect of Industry Growth

Projections of growth in the iron and steel industry have, in recent years, been invariably wrong. In 1974, for example, experts were predicting a phenomenal growth. At the present time, many experts are seeing a leveling off, or perhaps even a decline. Nevertheless, the current consensus is that a 2.5 percent growth in production appears to be reasonable.[37] IF steel industry production grows by 2.5 percent, then it is reasonable to expect that the generation of solid waste will grow by approximately the same amount.

TABLE 30. IMPACT OF FUTURE WATER REGULATIONS ON SOLID WASTE[19,38]

Operation	BPCTCA (1977)[a]	BATEA (1983)[b]	Product	New Sludge*
	(Suspended Solids kg/tonne)		(tonnes/yr)	(tonnes/yr)
Coke	0.0365	0.0104	48,500,000	1,266
Blast Furnace	0.0260	0.0130	81,300,000	1,057
Basic Oxygen	0.0104	0.0052	77,400,000	402
Electric Arc	0.0104	0.0052	27,900,000	145
Continuous Casting	0.0260	0.0052	15,300,000	318
Primary Mill	0.0371	0.0011	87,200,000	3,139
Hot Rolling	0.2420	0	84,800,000	20,522
Pickling	0.0469	0.0026	34,400,000	1,524
Cold Rolling	0.1042	0.1042	34,400,000	0
Galvanizing	0.1250	0.0104	5,300,000	607
Tin Plating	0.1250	0.0104	6,400,000	733
				29,713
Present Process Waste Landfilled		17,189,000 tonnes/yr[c]		
% Increase with 1983 Regulations		0.2		

*New Sludge = (BPCTCA - BATEA) x Product

[a] BPCTCA - Best Practicable Control Technology Currently Available

[b] BATEA - Best Available Technology Economically Achievable

[c] Landfilled waste excluding rubble and brick.

An estimate of waste generation is provided in Table 31 and is based on a yearly growth rate of 2.5 percent. The impact of air and water regulations that was discussed in previous sections has been included in the dust and sludge estimates.

TABLE 31. PROJECTED WASTE GENERATION IN 1983
(MILLIONS OF TONNES)

Waste	1977	1983
Slag	43.3	50.3
Dust, Sludge	6.4	7.6
Scale	6.3	7.3

In summary, the projection for growth in the generation of solid waste from iron and steelmaking is as follows:

1. from air regulations 0.5 percent,
2. from water regulations, 0.2 percent, and
3. from production growth, 2.5 percent per year.

7.0 THE ENVIRONMENTAL IMPACT OF IRON AND STEEL SOLID WASTES

This section describes the current waste disposal practices of the iron and steel industry and identifies sources of environmental impact from these practices. The impact of the criteria for sanitary landfills on the iron and steel industry is assessed and alternative disposal practices are identified which would be in compliance with Section 4004 of RCRA.

Solid wastes are currently defined to include not only solids and liquids which are not reused, but also solids and liquids which are reused if the material is placed into or on any land or body of water such that any constituent may enter the environment. This broad definition of solid waste could include such facilities as raw material storage, waste treatment lagoons, slag processing facilities, and leaking pipes or sewer lines. Although the environmental impact from each of these solid wastes cannot be assumed to be negligible, the only solid waste disposal which has been considered is conventional landfilling.

Current landfill operations are generally conducted such that any leachate which is formed may enter the groundwater, but some of the wastes have been put in lined landfills with leachate collection. Most of the nonhazardous waste is estimated to be disposed of on-site with approximately 30 percent disposed of off-site and 6 percent handled at contract disposal sites.

The water extract of various iron and steel wastes contain components which can, under some circumstances, endanger health when ingested in drinking water in high enough concentrations. Some of these components include oil, cadmium, chrominum, lead, mercury, phenols, and cyanide. There is a variability not only among different types of wastes, but also among various samples of the same type of waste. The proposed rules not only require the groundwater at the property boundary to meet any promulgated National Interim Primary Drinking Water Standard, but it also requires that the water not be made unfit for human consumption, which includes aesthetic as well as health factors not currently regulated.[53] The use of lined landfills for steel wastes with controlled discharge of the collected leachate is assumed, since this method of landfill operation would restrict the contamination of groundwater by the leachate.

7.1 TREATMENT AND DISPOSAL PRACTICES

The types of disposal practices utilized in dealing with steel industry solid wastes have been broken down into three categories: (1) reuse or recycling, (2) stockpiling for potential reuse, and (3) dumping with no intent for reuse. For the category of dumping, the general term "landfill" has been used to describe a solid waste dump site to avoid overlapping or ambiguous terminology. Within the disposal site may be pits, lagoons, ponds, basins, filled-in ravines, mounds, or heaps of varying size and number. These sites that are used by the steel industry are usually large land areas that receive solids, liquids, and sludges, and for the most part, are not lined facilities designed to prevent leachate movement with provisions for leachate collection and groundwater monitoring.

7.1.1 Slag Treatment and Disposal

Slag is a waste generated by iron and steelmaking but serves as a valuable raw material for the slag processing industry. It is processed at 101 major iron and steel furnace slag plants and also at an undetermined number of smaller plants Some of the major processors and their locations are listed below:[39]

International Mill Service (WV, PA, OH, IL)
U.S. Steel Corporation (WV, PA, OH, UT, IL)
Duquesne Slag (PA)
Heckett Co. (CA, IN, NY)
E.C. Levy Co. (MI, IN)
Buffalo Slag (NY)
Vulcan Materials (AL, IN)

Blast furnace (iron) slag is sold as three general physical types: air-cooled, granulated, and expanded. Air-cooled slag is produced by pouring molten slag into a slag bank or pit; after solidifying and cooling, the slag is excavated, crushed, and screened. Iron is magnetically removed and recycled. This type of slag is produced at 48 plants and accounts for 70 percent of the slag sold (Table 32).

TABLE 32. QUANTITY OF SLAG SOLD AND VALUE (1976)[39]

Type	# of Major Processing Plants	Millions of Tonnes	Millions of Dollars	Avg. Value $/tonne
Air-Cooled*	48	20.8	59.8	2.88
Granulated*	11	1.5	3.5	2.33
Expanded*	7	1.4	6.6	4.71
Steelmaking	35	6.0	9.7	1.62
TOTAL	101	29.7	79.6	2.68

*From blast furnace (ironmaking)

Approximately 10 percent of the blast furnace slag that is produced is landfilled; however, even in these cases it serves a constructive purpose. For example, one major plant is using its slag as on-site fill material for future plant expansion, but the site qualifies as a landfill due to the various wastes (e.g., dust and oily and organic sludge) mixed in during the dumping operation. Other plants pile the slag in mounds for future sale or use it to dike a landfill area. Some old slag dump sites are being mined to recover the slag to meet the increased demand.

Steelmaking slag is processed at 35 major plants but in much smaller quantities than ironmaking slag. This slag is usually water cooled, crushed, and iron is recovered for recycling. Steelmaking slag is sometimes recycled to the blast furnace to recover iron, manganese, and lime values, and finds some use in construction for unconfined bases, fill, and highway shoulders. Its utility is much more limited than ironmaking slag because it can undergo uncontrolled expansion due to hydration of free lime.[39] It is estimated that 45 percent of the steelmaking slag is used or recycled and that 55 percent is landfilled. The landfilled slag often is used for dikes, landfill bases, and for layering or mixing with dust and sludge.

Slag generation and disposition based on the national production of 125 million tonnes of steel per year is provided in Table 33 and indicates that over 13 million tonnes per year of slag is disposed of in landfills.

TABLE 33. SLAG DISPOSITION FROM 125,000,000 TONNES OF STEEL PER YEAR (THOUSANDS OF TONNES)

Source	Generated	Landfilled	%	Recycled, Used	%
Ironmaking	28,300	2,800	10	25,500	90
Steelmaking	19,360	10,560	55	8,800	45
TOTAL	47,660	13,350	28	34,300	72

A category for "stocked" slag was omitted due to the difficulty in determining the difference in landfilling (or dumping) and stockpiling. Many companies that may describe the disposal site as a stockpile have accumulated large quantities of slag over a period of years. A report prepared in 1976 for the Federal Highway Administration to examine the availability of wastes for use as highway materials estimated the quantities available at a few slag dump sites.[48] This information is listed in Table 34 and shows that six locations in Pennsylvania have 93.5 million tonnes (103 million tons) in slag piles.

TABLE 34. QUANTITIES OF SLAG AT SELECTED SITES[48]

Company	Location	Slag Type	Quantity (millions of tonnes)
U.S. Steel	Pittsburgh, PA	Iron	40.9
		Steel	18.2
Bethlehem	Bethlehem, PA	Steel	12.7
Lukens	Coatesville, PA	Steel	4.5
Bethlehem	Johnstown, PA	Steel	13.6
Slag Dump	Vanderbilt, PA	Iron	3.6
Bethlehem	Buffalo, NY	Steel	4.1
Kaiser	Fontana, CA	Iron and Steel	18.2

7.1.2 Sludge Treatment and Disposal

Sludge is generated by water treatment facilities in which solids are removed from process wastewater and from the water used in wet pollution control equipment. The wastewater goes through a series of treatments that may include settlers, thickeners, oil skimmers, scale pits, polymer addition to aid settling and dewatering, clarifiers, and filters. The type of treatment is plant specific and may involve almost any combination of the above for treating water from various processes individually or in central treatment plants. The resulting sludge is recycled, landfilled, stocked, or put into a lagoon for additional dewatering before disposal. The use of lagoons and holding ponds is widespread with each major plant having at least one such facility. A total of 16 lagoons and ponds were identified in 13 major plants, and each plant generated some sludge that was landfilled.[16,20]

Complete sludge disposition data was available from 17 plants. This data indicated that 13 plants practiced recycling, 10 had stockpiles on-site for potential reuse, and all 17 landfilled at least a portion of their sludge. The disposition of sludge is provided in Table 35 and is based on the national production of 125 million tonnes of steel. Sludge from the rolling mills and steelmaking furnaces accounts for 1.3 million tonnes of the estimated 1.6 million tonnes of sludge landfilled yearly.

TABLE 35. SLUDGE DISPOSITION FROM 125,000,000 TONNES OF STEEL PER YEAR[16,20] (THOUSANDS OF TONNES)

Source	Generated	Landfilled	%	Stocked	%	Recycled	%
Ironmaking	2,030	270	13	190	9	1,570	78
Steelmaking	1,170	617	53	286	24	267	23
Rolling Mills	758	730	96	---	--	28	4
TOTAL	3,958	1,617	41	476	12	1,865	47

Some of the techniques used by individual plants are listed below to illustrate the variety of sludge handling procedures.

Plant A - mixed with dust and slag in landfill

Plant B - spread over slag pile

Plant C - mixed with dust and scale, then stockpiled

Plant D - placed in pits in the landfill area, then covered with slag

Plant E - randomly dumped with organic sludge and other wastes in a large landfill

Plant F - placed in lined landfill with leachate collection

7.1.3 Dust Treatment and Disposal

Dust is collected by dry air pollution control equipment used in the sinter plant, blast furnace, and steelmaking furnaces. Estimates of dust generation and disposition are given in Table 36. Sinter and blast furnace dusts are generally recycled, but steelmaking dust is mostly landfilled and accounts for 73 percent of the 1.2 million tonnes of dust whis is not recycled.

TABLE 36. DUST DISPOSTION FROM 125,000,000 MILLION TONNES OF STEEL PER YEAR[16,20] (THOUSANDS OF TONNES)

Source	Generated	Landfilled	%	Stocked	%	Recycled	%
Sinter	740	40	6	---	--	700	94
Ironmaking	1,290	170	13	120	9	1,000	78
Steelmaking	1,050	690	66	190	18	170	16
TOTAL	3,080	900	29	310	10	1,870	61

Dust disposition data was available from 17 major plants and revealed that 16 practiced recycle, 6 had stockpiles on-site, and 7 landfilled a portion of their dust.

Some specific dust handling techniques practiced by individual plants are described below:

Plant G - mixed with scale and stockpiled

Plant H - mixed with water to prevent wind transportation and placed in a holding pond

Plant I - BOF dust is recycled by using select scrap in the BOF to keep zinc content down

Plant J - dust is "stored" in the ground by covering with a layer of dirt

Plant K - covered with BOF slag

7.1.4 Scale Treatment and Disposal

Scale is generated in the rolling operations and is usually collected in scale pits or settling basins. These settlers serve as a preliminary treatment of direct contact process water that is used for cooling, scale removal, and flushing. The heavy coarse pieces settle out and the very fine scale is removed in subsequent water treatment as a sludge.

Most of the scale generated in the rolling mills is recycled or stocked for potential recycling. Some of the stockpiled scale is not recycled immediately due to a high oil content that causes problems of hydrocarbon emissions and fouling of fabric filters in the sinter plant. In some cases this scale is sent through a de-oiling process prior to delivery to the sinter plant. Approximately 70 percent of the mill scale is recycled, 30 percent stocked, and a small quantity is dumped (Table 37). That portion disposed of in a landfill is generated by the cold rolling operation and has a high oil content, but it is only 0.04 percent of the mill scale produced.

TABLE 37. SCALE, DISPOSITION FROM 125,000,000 TONNES OF STEEL PER YEAR[16,20] (THOUSANDS OF TONNES)

Source	Generated	Landfilled	%	Stocked	%	Recycled	%
Soaking Pit	1,310	1,310	100	---	--	---	--
Rolling Mills	5,602	2	---	1,670	30	3,930	70
TOTAL	6,912	1,312	19	1,670	34	3,930	57

Soaking pit scale, also called soaking pit slag, is iron oxide scale fused with the coke breeze or dolomite (calcium magnesium carbonate) that has been placed in the bottom of the soaking pit. This scale may be contaminated with refractory or other material and is usually landfilled.

7.1.5 Miscellaneous Waste Treatment and Disposal

Plant debris, trash, rubble, and refractory from relining of furnaces are landfilled. AISI estimated that these wastes are generated at a rate of 10 percent of the steel produced (200 pounds per ton), so that the national production of 125 million tonnes of steel would give 12.5 million tonnes of this waste.[40] Eight plants reported to state agencies regarding the disposition of miscellaneous debris and the quantities totaled approximately 5 percent of the steel produced. In three cases the waste was disposed of by means of contract disposal, in another three at an off-site landfill, and in two at an on-site landfill.

Fly ash and bottom ash (or clinker) are solid wastes generated in coal-fired boilers. In many cases the boilers are fueled with coke oven and blast furnace gases supplemented by oil or natural gas. The use of these fuels does not produce a solid waste. However, Dravo found that three of the ten plants visited used one or more coal-fired boilers that generated fly ash and bottom ash.[20] Information on these wastes was obtained from state agencies for six plants and their rate of generation was approximately 13 kg per tonne of steel. Two of these plants landfilled the ash on-site and the other four off-site.

Grinding and scarfing dust arises from the removal of surface defects during the finishing operations. Battelle estimated in 1976 that there were 43 facilities with air pollution controls on these surface finishing operations.[41] The quantity of dust as reported by Dravo ranged from a negligible amount to 0.1 percent of the steel produced, and was unknown in three of the six plants reporting this waste.[20] Based on the Dravo report, the quantity of this waste generated and landfilled is believed to be small.

Spent pickle liquor was discussed briefly in Section 6.1.7 and the sludge from neutralization was estimated as 350,000 (dry) tonnes per year.[20] An estimated 800,000 tonnes of pickle liquor solution is generated from the overall production of 125 million tonnes of steel.[16] An EPA survey revealed that over 60 percent of the spent liquor was disposed of without treatment.[19] A change from deep-well disposal to neutralization would, therefore, cause a significant increase in the amount of sludge that must be disposed of in landfills. The disposal problem is complicated by the fact that hydrated metal oxides from the neutralization process usually will not dewater to more than 10-20 percent solids, so this sludge is not really a solid but a pseudoplastic fluid.[42] The previously cited EPA document states that the pickling of one million tons of steel, upon neutralization of the spent pickle liquor, could result in 200,000 tons of wet sludge, which would require 150 acre-feet of permanent fill volume.[19]

In Pennsylvania, most pickle liquor is handled by two contract haulers who use the following disposal technique:[43]

1. Pickle liquor is placed in a lagoon and neutralized;
2. The liquid is floated off and the sludge is left in place in the unlined lagoon, and
3. When the lagoon is full, it is covered with a sloping top of soil and revegetated.

7.2 CURRENT DISPOSAL FACILITIES

7.2.1 Prevalence of Types of Disposal Practices

Published data was reviewed and supplemented with data from state agencies to obtain estimates of the number of disposal sites and percentages of wastes disposed of on-site, off-site, and by contract disposal. The data base for the prevalence of different types of sites consisted of the 13 plants visited by Dravo[20] and Calspan[16] and 20 plants for which information was provided by state agencies in Pennsylvania, Indiana, Maryland, Michigan, and Ohio. The various disposal facilities for the 33 plants included 28 on-site, 11 off-site, and 10 contract disposal sites. The total for contract disposal does not include slag processors or those contractors handling spent pickle liquor only.

The use of on-site landfills appears to be a function of plant location and land availability. Many plants located in Chicago and Pittsburgh have off-site dumps, use contract haulers, and only use available plant property for stocking wastes for potential recovery. Plants located in Indiana, California, Alabama, New York, and some areas of Pennsylvania take advantage of available on-site or nearby off-site property for landfills. For example, a company in the Pittsburgh area has one large off-site landfill serving four plants, while in eastern Pennsylvania another extensive steelmaking complex has five landfills on its own property.

Contract disposal is used routinely in combination with on- or off-site disposal. Based upon a sample of 10 contract haulers, the types of wastes eliminated via contract disposal (excluding slag, oil, pickle liquor) were:

plant rubble, debris, miscellaneous wastes (4), sludges (4), and soaking pit slag (2). The contractors and their locations are listed below:

Bairstol Central Teaming Co. (IL)
Browning-Ferris Industries (PA)
Cinders Co. (IL)
E.C. Levy Co. (MI)
Indiana Sanitation Co. (IN)
Industrial Disposal (IN)
Liquid Engineering Co. (IL)
Pittsburg and Lake Erie
  Railroad Co. (PA)
Sanitary Landfill Co. (PA)
Vogel Co. (PA)

Complete data on the quantities of waste disposed of by each method was available for 17 plants. These quantities were summed and the percentage of total nonhazardous waste eliminated via each of the three disposal categories was estimated as 65 percent on-site, 29 percent off-site, and 6 percent by contract disposal.

7.2.2 Estimate of the Number of Landfills

To estimate the number of major landfill sites, it was necessary to establish the number of major iron and steelmaking plants. A review of the industry revealed that there were approximately 50 plants using blast furnaces, basic oxygen furnaces, or open hearths (often in combination with electric arc furnaces). In addition, 13 of the 103 plants using only EAF's have capacities exceeding 500,000 tonnes of steel per year and were arbitrarily included as major plants. The total of 63 major plants to be used as the basis for estimating the number of landfills account for more than 90 percent of steel production.

The estimate of landfill sites for these plants included 53 on-site, 21 off-site and 19 off-site landfills belonging to contract haulers. Details of this estimate and the data base are provided in Table 38. Disposal by contractors does not include slag, pickle liquor, or waste oil processors.

The data base used for estimating the percent of total waste going to each type of landfill was explained in Section 7.2.1 and included 17 plants for which complete quantity and disposiation data were available.

TABLE 38. ESTIMATE OF MAJOR LANDFILLS

	Data Base	Estimate for Total	% of Total Waste
No. of Major Plants	33	63	> 90
On-Site	28	53	65
Off-Site	11	21	29
TOTAL	39	74	94
Contract Disposal*	10	19	6

*Excludes slag, pickle liquor, and waste oil processors

7.2.3 Present Disposal Costs

Present disposal costs of solid wastes are variable due to differences in land and transportation costs, mode of operation, landfill size, and quantity of waste landfilled. Some typical costs (including capital, operating, and maintenance costs) are given in Table 39 and show a range of $0.82 to $5.50 per tonne for most wastes.

TABLE 39. LANDFILL COSTS

Cost ($ per tonne)	Reference	Comments
0.82 - 5.50	Mantell[44]	Sanitary landfill
4.40	A.D. Little Co.[11]	Average of all waste disposal
1.10 - 5.50	Chester Engineers[45]	Sanitary landfill
1.65+pickup+transportation	Private contractor[46]	Natural clay base
4.40 - 11.00	Chester Engineers[45]	Pickle liquor by contractor
20.00 - 24.00	Calspan Corp.[16]	Oily wastes by contractor

A private contract disposal company stated that their basic disposal charge for material brought to their fill site (with a natural clay base) is $1.65 per tonne ($1.50 per ton). By private contract with the steel mills, other items are priced to include pickup, processing for scrap removal, hauling, and dumping. These rates would be added to the basic charge and are confidential.[46] The charges for pickup and transportation alone could double the basic disposal charge.

A.D. Little reported an average disposal cost of $4.40 per tonne ($4.00 per ton), but noted that the costs varied significantly among the 130 steel plants in their survey.[11] Chester Engineers' study of wastewater residue management in Allegheny County (PA) estimated that the cost for disposal in landfills ranged from $1.10 per tonne for a 5,000 tonne per day operation to $5.50 per tonne for a 60 tonne per day operation. The same study reported the cost of pickle liquor disposal by contract hauler as $4.40-$11.00 per tonne ($0.02-$0.05 per gallon); this includes neutralization and disposal in a lagoon.[45] The costs for oily wastes handled by contract haulers is provided for comparison and may range up to $20-$24 per tonne ($0.10-$0.12 per gallon).[16]

In estimating present disposal costs, it is assumed that nonhazardous wastes are disposed of in unlined landfills. Although some claim to have a clay base, few have provisions for leachate collection. One exception that was discovered in the survey of state solid waste agencies was in Pittsburgh, Pennsylvania, where lined impoundment with leachate collection is required for some nonhazardous wastes before a new landfill site is approved.

For most of the large steel companies, the on-site dumping costs are estimated at $1.20 to $2.00 per tonne (average of $1.60) and off-site costs are estimated at $2.00 to $3.00 per tonne (average of $2.50). Disposal at the contractor's site was estimated at $3.30 per tonne by doubling the basic charge of $1.65 to include pickup and transportation. Disposal of spent liquor was estimated at $7.70 per tonne as the midrange of the values in Table 39.

An estimate of the amount of solid waste landfilled is provided in Table 17 and totaled 17.3 million tonnes of process waste and about 12.5 million tonnes of miscellaneous wastes to give a total of 29.8 million tonnes. A breakdown of estimated disposal costs is provided in Table 40 by disposal location and includes pickle liquor since this is a relatively large volume of waste. The total cost to the industry for disposal of major solid wastes is approximately $65 million.

TABLE 40. COST ESTIMATE OF PRESENT DISPOSAL

Disposal Type	Quantity (tonnes of millions)	Estimated Cost ($ per tonne)	Total Cost ($ millions)
On-site	19.4	1.60	31.0
Off-site	8.6	2.50	21.5
Contractor	1.8	3.30	5.9
Pickle liquor by contractor	0.8	7.70	6.2
		TOTAL	64.6

7.3 ENVIRONMENTAL AND HEALTH ASSESSMENT OF CURRENT DISPOSAL PRACTICES

Present disposal practices include recycling or reuse, stockpiling, and landfilling. The major impacts on the environment from the latter two methods result from wind transportation, surface run-off, and subsurface migration of leachate.

Wind transportation of dusts from storage piles and landfills can be minimized by proper attention to configuration (exposed surface area), topographic location (windbreak, despressions), moisture content, and spraying with various chemicals.* Surface run-off can likewise be controlled by proper attention to location, climate, and method of operation. Of primary interest in the environmental assessment of solid waste disposal is the subsurface migration of leachate. The balance of this section will deal with leachate characteristics and assessment with respect to criteria outlined in RCRA.[52,53]

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*The method of transporting the dusts is important. Open trucks tend to redisperse them.

7.3.1 Water Quality Requirements of RCRA

The major impact of RCRA on the waste disposal practices of the iron and steel industry is the potential damage to the groundwater. Groundwater criteria provide for the prevention of endangerment at the property boundary of the disposal site.[52] Endangerment is defined as the introduction of any substance into the groundwater in such a concentration that additional treatment is necessary for a current or future user of the water, or the water is unfit in any way for human consumption.[53] Maximum contaminant levels are set forth in promulgated National Interim Primary Drinking Water Standards.

Table 41 lists various permissible criteria of selected leachate components in drinking water. Contamination beyond these limits makes the water undesirable for human consumption. Organic leachate components are also of concern because certain coke plant wastes are known to contain polycyclic aromatic hydrocarbons. National standards for suspected carcinogens such as polycyclic aromatic hydrocarbons have not been promulgated due to a lack of information about health effects.[57] Specific organic compounds which are currently monitored have been selected on the basis of the likelihood of occurrence in treated water, the toxicity data, and availability of practical analytical methods. EPA is actively investigating suspected carcinogens and future water standards may reflect this activity. The World Health Organization drinking water standards permit only 0.0002 mg/ℓ of polynuclear aromatic hydrocarbons.[55] Pennsylvania Department of Environmental Resources data indicate that from 3-10 mg/ℓ of oil and grease (organics) are found in the extracts of most iron and steel wastes.

One of the major ways that RCRA serves to manage waste disposal facilities is the elimination of hazardous waste from the nonhazardous waste disposal facility. Elimination of these hazardous materials from the landfill site reduces the required treatment of the leachate and could reduce the potential health hazard if the liner for the landfill were to fail. For these and other reasons, one of the criteria for classification of hazardous waste is the potential for a component to leach out in concentrations 10 times that of drinking water standards. One major consideration for the special designation of a waste as hazardous is to assure that such waste is delivered to a landfill which conforms to proper management practices.

TABLE 41. PERMISSIBLE CRITERIA FOR SELECTED COMPONENTS FOR PUBLIC WATER SUPPLIES.

Constituent	Permissible Criteria (mg/ℓ)
pH	6.0-8.5[b]
Arsenic	0.05[a,b]
Barium	1.0[a,b]
Cadmium	0.010[a,b]
Chromium	0.05[a,b]
Fluoride	1.2 (63.9-70.6°F)[b]
Iron (filterable)	0.3[b]
Lead	0.05[a,b]
Manganese (filterable)	0.05[b]
Selenium	0.01[a,b]
Silver	0.05[a,b]
Total dissolved solids	500.0[b]
Zinc	5.0[b]
Carbon chloroform extract	0.15[b]
Cyanide	0.2[b]
Oil and grease	Virtually absent[b]
Phenols	0.001[b]
Mercury	0.002[a]

[a] National Interim Primary Drinking Water Regulations[57]

[b] Water Quality Criteria, Department of Interior, FWCPA[54]

7.3.2 Water Extraction of Solid Waste Materials

Water extraction tests were reported by six plants to PDER (Code A, B, E, F, G, and H) as well as from an EPA survey[58] (C) and ASTM[15] (D). These tests differ from the proposed EPA Extraction Procedure in that distilled water was used, whereas the proposed EPA procedure uses a limited amount of acetic acid for pH control. Higher levels of heavy metals are expected from these tests when acetic acid is used. The ASTM leachate values were reported by Enviro Control[15] with additional ASTM testing provided by AISI. Although ASTM tested the wastes with several different types of water, only the 48 hour extraction with carbon dioxide saturated reagent water is included in this report.

Coke plant wastes include coke breeze, tar sludges, and pitches from various tar storage and processing operations, ammonia still lime sludge, cooling tower sludge, and biological treatment sludge. Due to the widely diverse processes which can be used to treat the coke by-product gases, the number of wastes, the amounts generated, and even the composition are expected to vary from plant to plant. In general, coke plant wastes are expected to be hazardous with the possible exception of coke breeze. The results of the aqueous extraction of four coke plant wastes are presented in Table 42. With the exception of pH, the results are best expressed as the ratio of the amount of material in the extract divided by the permissible criteria (i.e., number of times drinking water standards). The permissible criteria used to develop Table 42 was the largest concentration presented in Table 41 and may differ from legal requirements. This approach is used to provide a uniform method for assessing potential aesthetic and health impacts on the environment from leachate, and is not used for the classification of a waste as hazardous.

The tar decanter sludge contains relatively large amounts of oil and grease as well as phenols. Ammonia still lime sludge contains cyanides, phenols, and may contain polycyclic aromatic hydrocarbons in concentrations high enough to be of concern. The water extract from cooler sludge contained relatively large amounts of oil and phenols. Some tar is also expected in the oil from the extract. In general, coke plant waste should be given special consideration because of the carcinogenic nature of the coke oven gas from which they originate and the potential of phenols and cyanides to endanger the groundwater. Most coke plant solid wastes are hazardous and require segregation from nonhazardous wastes.

Slags are the major solid waste generated by the iron and steel industry. They are commonly used in a variety of fill applications as well as being disposed of in landfills. The results of aqueous extraction tests for various iron and steelmaking slags are presented in Table 43. Although the results are generally incomplete, a number of conclusions can be drawn. The steelmaking slags from the BOF, the open hearth, and the EAF are generally of more environmental concern than the blast furnace slag. For example, the pH is much

TABLE 42. RESULTS OF AQUEOUS EXTRACTION TESTS OF COKE PLANT WASTES. (Results are expressed in the amount detected divided by the permissible criteria. No analysis designated X.)

	Solids	pH (units)	Oil	Phenols	Cyanides	Cd	Cr	Pb
Tar Decanter Sludge C	X	8.9	1320.0	5×10^5	3.0	X	<0.2	< 4.0
A	0.36	7.8	60.0	1.3×10^5	<0.04	<3.2	<3.7	9.6
Ammonia Still Lime Sludge C	X	11.5	X	2×10^4	990.0	X	0.4	10.0
Cooler Sludge A	0.12	6.7	60.0	12×10^5	0.2	<4.0	<2.2	<10.2
Coke Breeze, Mine Refuse G	0.2	10.4	33.0	0.0	0.0	0.0	0.0	0.0

TABLE 43. RESULTS OF AQUEOUS EXTRACTION TESTS OF IRON AND STEEL SLAGS. (Results are expressed in amount detected divided by permissible criteria. No analysis designated X.)

Material	Source	Solids	Oil	Cd	Cr	pH (units)	Pb	Phenol
Blast Furnace Slag	A	3.7	20	<3.2	<3.7	5.0	<4.4	< 5
	B	X	X	1.3	0.0	8.8	1.2	X
	C	X	X	X	<0.2	10.6	<4	X
	D	X	X	<1.0	<1.2	X	1-4.6	X
	D	3.7	X	<1.0	0.6	11.9	3.6	X
	D	X	X	<1.0	<1.0	10.1	1.0	X
BOF Slag	A	2.2	27	<3.2	<3.7	12.2	<4.4	<23
	E	0.3	X	<2.0	<1.0	12.5	7.0	<26
	F	0.7	30	0.0	4.2	9.4	0.0	0.0
	C	X	X	X	3.0	12.5	4.0	X
	D	X	X	<1.0	<1.0	9-11	<0.2-1.6	X
	D	1.4	X	<1.0	<0.2	9.0	1.2	X
	D	1.3	X	X	X	12.4	X	X
Open Hearth Slag	C	X	X	X	1.0	12.5	6.0	X
	D	X	X	<1.0	0.0-2	X	0-3.0	X
	D	X	X	1.0	2.0	11.0	3.0	X
	D	3.5	X	0.0	0.0	12.5	0.0	X
EAF Slag	C	X	X	X	5.4	12.4	8.8	X
	D	X	X	0.0	2.2-6.4	X	0.0	X
	D	0.65	X	0.0	5.2	11.0	0.0	X

higher for steelmaking slags than blast furnace slags. Leachate components of possible concern are organic materials, chromium, lead, and phenols. Steelmaking slags require special consideration because of the high pH. Heavy metal components in the leachate are a function of the acidity of the water in contact with the slags.

Iron oxide wastes include dust and sludges from air pollution control facilities. Some of the water extraction tests on the sludges are presented in Table 44, and data from the dust are presented in Table 45. It is interesting to note that oil and grease were found whenever the extract for oil was examined. Relatively large amounts of phenols were found in the blast furnace sludge and dust. The extract from BOF dust also contained phenols.

The extract from air pollution dust and sludges was examined for many of the wastes. For each waste examined, the extract did not meet drinking water standards when only three metals were considered. This causes concern for the potential for groundwater endangerment. In some cases, however, the test results were inconclusive. Based upon these data, iron and steelmaking dust and sludges should be landfilled with leachate collection wherever the groundwater needs protection.

Additional iron and steel wastes are presented in Table 46 with the results of the extract testing. With the possible exception of grate ash which was incompletely tested, the extract from the wastes did not meet the National Interim Primary Drinking Water Standards. A high level of chromium was reported in the melt shop rubble, slab dust, mill scale, and soaking pit slag. Relatively high levels of oil and grease were reported whenever the extract was tested for organic extracts. The acid rinse sludge and the slab grinder dust contained relatively high levels of phenols. For these reasons most of the miscellaneous wastes reported in Table 46 may require the use of a lined landfill wherever the leachate may endanger the groundwater.

7.3.3 General Information on Soil Attenuation and Leachate Movement

The previous section discussed water extraction results of steel wastes that are used to estimate leachate composition. However, for the purpose of assessing the impact of leachate on the environment, it is important to understand the mechanisms that may alter the leachate and the factors that affect the accurate measurement of this impact on groundwater.

TABLE 44. RESULTS OF AQUEOUS SOLUBILITY TESTS OF IRON AND STEEL SLUDGES. (Results are expressed in amount detected divided by the permissible criteria. No analysis designated X.)

Material	Source	Solids	pH (units)	Oil	Phenols	Cyanides	Cd	Cr	Pb
Blast Furnace Sludge	A	1.6	9.5	67.0	14.0	25.0	3.2	3.34	4.0
	C	X	9.5	X	400.0	X	X	0.4	4.0
BOF Sludge	G	0.7	9.6	X	X	X	X	3.6	X
	C	X	10.4	X	X	X	X	1.8	4.0
	H	X	11.0	X	X	X	X	1.4	X
Open Hearth Sludge	D	X	5.4-6.9	X	X	X	1.0	1.0	1.0-2.0
EAF Sludge	C	X	11.5	X	X	X	X	1880.0	40.0

TABLE 45. RESULTS OF AQUEOUS SOLUBILITY TESTS OF IRON AND STEEL DUSTS. (Results are expressed in amount detected divided by the permissible criteria. No analysis designated X.)

Material	Source	Solids	pH (units)	Oil	Phenols	Cyanides	Cd	Cr	Pb
Blast Furnace Dust	A	X	11.7	X	250	<1.5	X	0.6	5.0
Open Hearth Dust	C	X	8.9	X	X	X	X	0.6	8.0
	B	X	7.2	X	X	X	255	0.0	18.0
	D	X	6.3-7.2	X	X	0.02-0.4	63-360	0-1.0	12-30
	D	19.0	6.8	X	X	X	330	0.0	66.0
EAF Dust	B	X	11.9	X	X	X	3.5	2400	3.2
	C	X	12.6	X	X	X	X	6.8	3000
	G	15.0	7.0	13.0	0	4.2	353	25,000	6.0
BOF Dust									
Precipitator	A	8.0	12.4	53.0	28.0	0.4	<3.2	<37.4	<4.4
Baghouse	A	10.4	8.2	20.0	40.0	0.03	<3.2	9.52	8.2
	E	0.8	12.5	X	X	X	X	2.0	142
	D	X	11.5-12	X	X	X	<1.0	25-66.4	3.8-4.8
	D	X	12.5	X	X	X	<1.0	< 2.0	30-38
	D	6.1	12.1	X	X	X	1.0	25.2	4.8
	D	X	12.5	X	X	X	<1.0	< 0.2	38.4

TABLE 46. RESULTS OF AQUEOUS SOLUBILITY TESTS OF MISCELLANEOUS IRON AND STEEL WASTES. (Results are expressed in the amount detected divided by the permissible criteria. No analysis designated X.)

Material	Source	Solids	pH (units)	Oil	Phenols	Cyanides	Cd	Cr	Pb
Melt Shop Rubble	G	0.6	11.3	37.0	0.0	0.0	0.0	26.6	0.0
Slab Grinder Dust	G	0.14	6.6	43.0	150.0	0.0	0.0	0.4	0.0
Slab Dust	G	1.6	4.9	27.0	0.0	0.0	4.0	308.0	0.0
Incinerator Ash	G	0.5	10.2	20.0	0.0	0.0	0.0	1.0	0.0
Grate Ash	B	X	8.0	X	X	X	0.0	0.0	0.0
Boiler Bottom Ash	D	X	6.5	X	X	X	X	X	X
	B	X	8.4	X	X	X	0.0	0.5	3.6
Fly Ash	D	7.7	4.9	X	X	X	X	<0.2	12.4
	D	X	7.8	X	X	X	<5.0	X	<6.0
Mill Scale	G	X	8.7	X	X	X	X	34.8	0.0
	G	0.37	11.1	50.0	0.0	0.0	0.0	0.6	0.0
	C	X	9.6	3.3	X	X	X	1.0	<4.0
Soaking Pit Slag	C	X	9.5	X	X	1.9	X	28.0	<4.0
Wastewater Sludge	G	0.20	6.8	157.0	0.0	0.0	0.0	2.4	0.0
Lagoon Sludge	D	0.1	7.2	2.6	X	X	6.3	<10.0	X
Hot Mill Sludge	C	X	6.6	X	0.0	0.0	0.0	2.4	0.0
Acid Rinse Sludge	G	X	X	X	55.0	0.0	0.0	0.2	0.0

TABLE 46. (cont'd)

Material	Source	Solids	pH (units)	Oil	Phenols	Cyanides	Cd	Cr	Pb
Settling Basin Sludge	D	X	7.3	X	X	X	<1.0	<1.0	3.0
Brick Bat Material	D	0.7	6.4	X	X	X	X	X	X
Scrubber Slurry	D	2.1	9.24	X	X	X	X	X	X

As leachate moves through subsurface soils, several mechanisms can affect the nature and, consequently, the environmental impact of the leachate. One of these is ion exchange and adsorption by clay and organic soils that may adsorb and retain metallic ions. For example, the cations of sodium, potassium, magnesium, iron, manganese, and ammonia may be attenuated by cation exchange reactions on adsorptive surfaces in soil. Another mechanism is metal fixation in which metal ions bind irreversibly to the soil, or substitute with other ions of similar radii in the mineral structure. Metal cations can also react with phosphate, carbonate, or sulfide to yield a precipitate of low solubility.[47] Heavy metals in their metallic state are generally insoluble, but the heavy metal salts (as from electroplating or pickling), may be quite soluble. Ammonia that is present in leachate is oxidized to nitrate under aerobic conditions by certain bacteria and may be nitrate by the time it reaches groundwater.

The fate of organic leachate constituents is not well documented since few have been identified and their toxicity is unknown. Organics may come directly from the solid waste or from decomposition products and are probably subjected to adsorption and microbial degradation.[50]

These mechanisms are described to show the fate of some leachate constituents and not as a means of groundwater protection. They are often unpredictable in their effect, and once the soil capacity for a particular mechanism has been exceeded, a constituent may have an unobstructed path to the groundwater.

Some other factors that affect leachate movement and consequently affect monitoring and sampling requirements for environmental assessment are summarized below:

1. Geohydrologic conditions: Under some circumstances leachate will percolate rapidly, as through coastal plains sand, or through channels that may have developed in limestone. In other cases, it may move only a few feet per year through soils of low permeability.[49]
2. Climatic conditions: Leachate will move differently depending on whether or not the soil is frozen, the amount of annual precipitation, and frequency of brief periods of intense rainfall in a dry climate. In some states with over 70 percent of the steel wastes (IL, IN, MI, PA, OH), the annual rate of rainfall exceeds the potential rate of evapotranspiration by 5-20 inches per year.[47]

3. Disposal methods: The type of disposal method, whether lagoon, pit, dump, or landfill and the site preparation affect the rate of leaching.
4. Type of wastes: Some important waste types are (a) solid, sludge, or liquid (as in a lagoon with a continuous leachate plume), (b) organic or inorganic, and (c) water soluble or insoluble. For those components lighter than water, placement of wells is critical in that leachate may float on top of the zone of saturation and move past the sample well inlet.
5. Age of site: This is relevant in that leachate percolation may take several months to reach the groundwater.
6. Miscellaneous: Some cases may require more than the minimum of three wells when there is more than one aquifer, or where complex geologic or groundwater flow conditions exist. The influence of nearby wells, changes in aquifer depth, and groundwater velocity also affect leachate migration and required sampling frequency.[50]

The effects of these factors are shown graphically in Figure 18 which illustrates the importance of locating ponds (or lagoons), streams, and underlying geologic structure. Climatology, surface runoff, discharge zones, and aquifer recharge are other factors that are shown to affect the complex interrelationship of the hydrologic system and must be considered in locating or evaluating landfill sites.

Figure 19 is presented to underscore the need for a scientific study of a landfill site. The confident placement of groundwater wells (labeled GW-1, GW-2, GW-3) may provide a false security while the dangerous leachate plume is moving undetected into the groundwater.

7.3.4 Groundwater Analysis From Iron and Steel Landfills

Groundwater analysis was provided to PDER by several iron and steel companies in Pennsylvania (Table 47). When these results are compared with the leachate from individual wastes, both the groundwater and leachate extract contain large quantities of oil and grease. There is also close agreement in pH since the average pH of the leachate extract differs from the groundwater monitoring data by only 0.2 pH units. The problems with the water in meeting drinking water standards include alkalinity (high pH), excessive dissolved solids, and significant amounts of chromium. The overall quality of the groundwater was difficult to assess because of the lack of testing for heavy metals such as cadmium, and for the composition of the organic material in the extracts.

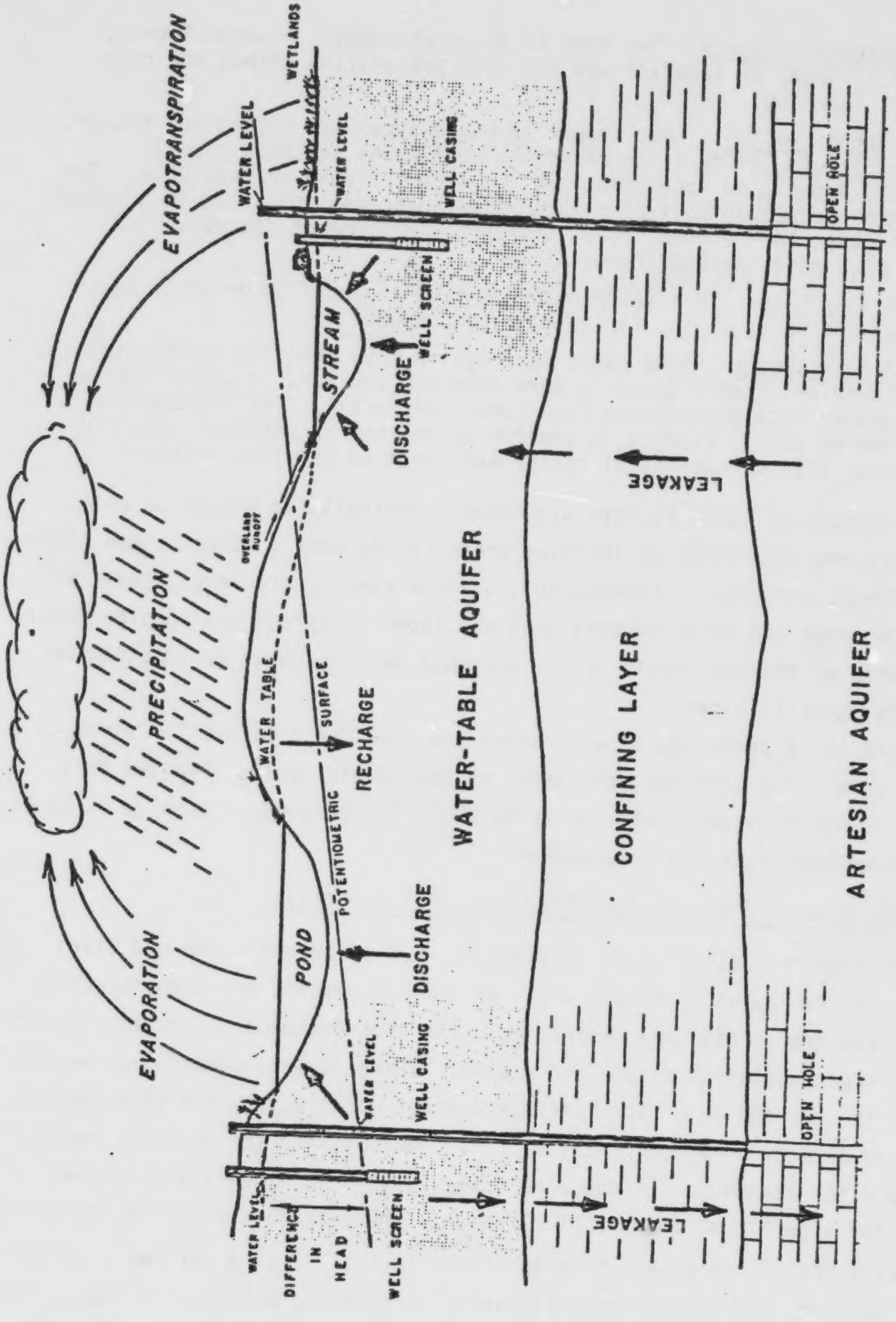


Figure 18. Illustration of relationships within the hydrologic system.[51]

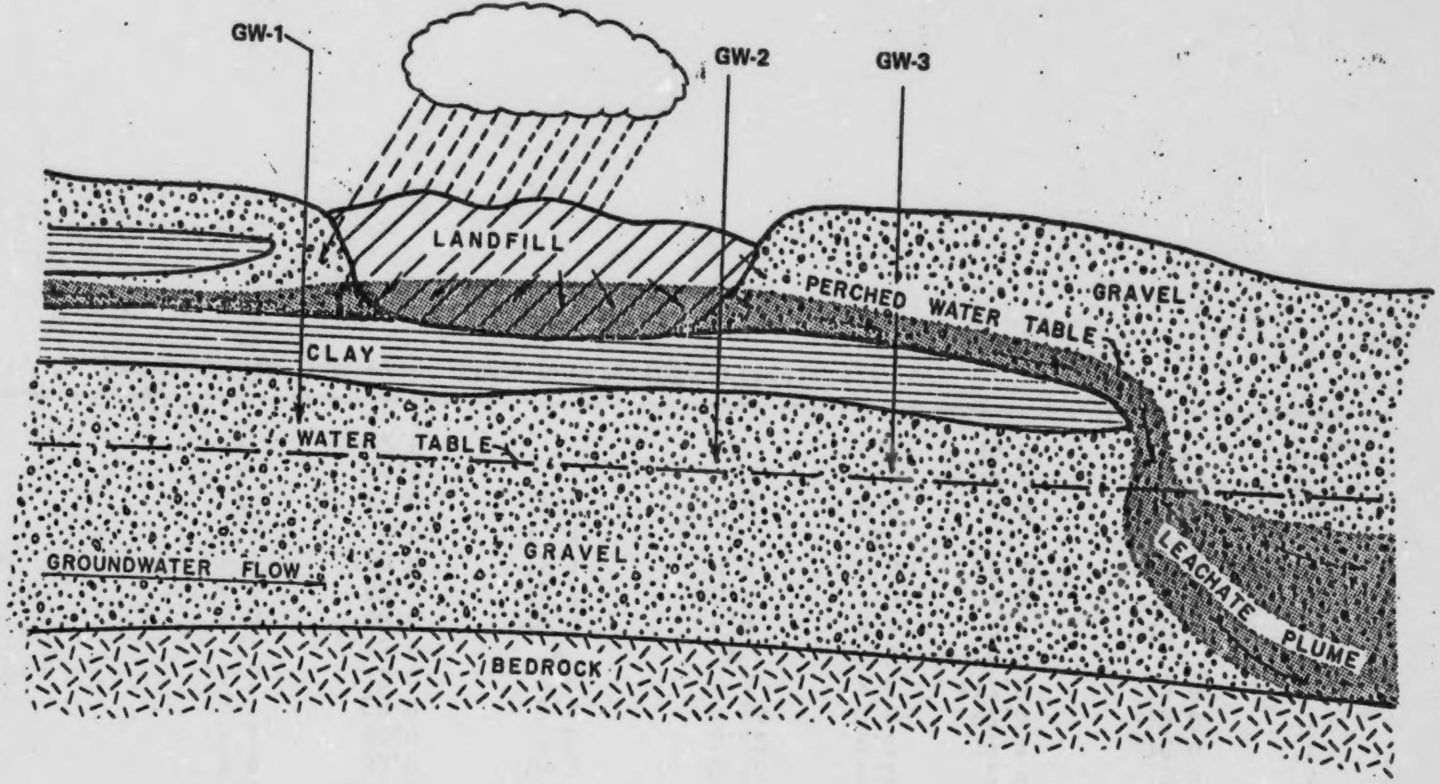


Figure 19. Abandoned gravel pit with a clay layer at its base.[50]

TABLE 47. SELECTED LEACHATE COMPONENTS IN THE GROUNDWATER OF VARIOUS IRON AND STEEL WASTE LANDFILLS. (Results expressed in amount measured divided by permissible criteria.* No analysis designated X.)

Site, Sample Position	Solids	Oil	pH (units)	Ammonia	Cr	Mn	Phenols	Cd
A,1	4.5	206.0	7.5	0.1	0.8	54.0	<12.0	X
A,2	4.2	100.0	7.7	0.34	0.8	26.4	<13.0	X
A,3	3.9	33.0	10.3	0.18	1.2	2.2	<10.0	X
A,4	5.1	40.0	7.5	0.22	2.2	72.2	<10.0	X
A,5	5.1	60.0	7.4	0.24	0.8	97.0	<10.0	X
A,6	6.3	120.0	7.5	0.1	2.6	117.0	<13.0	X
A,7	X	13.5	X	X	1.2	6.0	X	0.0
B,1	5.0	60.0	12.3	6.4	0.8	2.2	<10.0	X
B,2	5.8	67.0	12.3	<5.8	1.0	1.8	<30.0	X
B,3	5.4	120.0	12.1	4.5	0.8	2.2	<10.0	X
C,1	1.6	0.53	11.4	X	X	X	4.9	<2000
D,1	X	81.0	12.2	1.8	0.4	0.0	X	X
E,1	X	14.9	X	X	0.8	0.2	X	0.0
E,2	X	22.5	X	X	0.6	10.0	X	0.0

*This is equivalent to "number of times permissible criteria."

Five water samples were obtained from two landfill sites for additional testing. These sites are discussed in detail in Section 7.3.5 as plants A and E. Plant A provided water (A,7) from a seepage spring that was suspected of containing leachate from the landfill. A well located at the edge of landfill E and at the highest elevation in the site was sampled (E,1). A valley well was sampled, located 250 ft below and 1600 ft south of the well, at the edge of the site at the head of a stream (E,2). This well is also at the edge of, and 200 ft below the top of an established slag dump. A stream which enters the site was sampled (E,3), together with a downstream sample (E,4). This particular stream collects the drainage from the site.

The purpose of this sampling was to obtain information concerning groundwater pollution from iron and steel solid wastes. The state agency involved received some information about groundwater quality at these sites. This investigation provided a more detailed groundwater analysis, with particular emphasis on the organic chemicals in the groundwater, and a total elemental analysis by spark source mass spectrometery.

The water samples were subjected to a solvent extraction scheme developed by RTI that separates the sample into six fractions: acids, bases, insolubles, nonpolar neutrals (NPN), polar neutrals (PN), and polynuclear aromatics (PNA). Each of these fractions, except the insolubles, were subjected to gas chromatograph, mass spectrometer analysis. This was done for each groundwater sample.

Tables 48, 49, and 50 indicate the number of compounds found in each fraction, the lowest and highest concentration of the individual compounds, and the total concentration of compounds in each category. The mass spectra of the fraction which separates the PNAs indicated that most of the components are not PNA's.

The PNA fractions from the five water samples were subjected to a naphthalene sensitized PNA fluorescence test as prescribed by EPA (Table 51). This test is sensitive and detected low levels of PNAs in the groundwater at the property boundary (E,1), the upstream sample (E,3), the downstream sample (E,4), and the groundwater seepage (A,7). The upstream site (E,3) is about 1.5 KM from a very large slag dump that is the highest elevation point of the region. Although the levels detected were reliable only within a factor of 3,

TABLE 48. ANALYSIS OF GROUNDWATER FROM THE PROPERTY BOUNDARY (E.1)

Compound Category	No. of Components	APPROXIMATE CONCENTRATION (ppb) Range of Single Component	APPROXIMATE CONCENTRATION (ppb) Total
Acid (A)	4	13-38	106
Base (B)	5	24-100	284
Polar Neutral (PN)	0	---	---
Nonpolar Neutrals (NPN)	15	20-565	1633
Polynuclear Aromatics (PNA)*	8	10-41	200
SAMPLE TOTAL			2223

*The components found in this fraction are not PNAs. They are probably NPNs.

TABLE 49. ANALYSIS OF GROUNDWATER FROM VALLEY WELL BELOW SLAG DUMP (E.2)

Compound Category	No. of Components	APPROXIMATE CONCENTRATION (ppb) Range of Single Component	APPROXIMATE CONCENTRATION (ppb) Total
Acid (A)	6	29-96	343
Base (B)	4	30-105	260
Polar Neutral (PN)	12	35-51	484
Nonpolar Neutral (NPN)	17	16-533	2237
Polynuclear Aromatics (PNA)*	4	7-17	48
SAMPLE TOTAL			3372

*The components found in this fraction are not PNAs. They are probably NPNs.

TABLE 50. ANALYSIS OF SEEPAGE SPRING WATER FROM A DUMPSITE (A,7)

Compound Category	No. of Components	APPROXIMATE CONCENTRATION (ppb) Range of Single Component	Total
Acid (A)	4	40-70	246
Base (B)	5	17-42	152
Polar Neutral (PN)	6	6-10	45
Nonpolar Neutral (NPN)	16	18-296	887
Polynuclear Aromatic (PNA)*	21	13-67	703
SAMPLE TOTAL			2033

*The components found in this fraction are not PNAs. They are probably NPNs.

TABLE 51. POLYNUCLEAR AROMATIC FLUORESCENCE ANALYSIS

Sample	Unsensitized	Sensitized	PNA Spot Concentration	PNA Sample Concentration*
E,1	None	Very light	1 ng/μl	3 ppb
E,2	None	None	< 1 ng/μl	< 3 ppb
E,3	None	Very light	1 ng/μl	11 ppb
E,4	None	None	< 1 ng/μl	< 3 ppb
A,7	None	Strong	1-10 ng/μl	3-30 ppb

*GC/MS analyzed indicated no PNAs at the 10 ppb level.

the concentrations were 15 to 55 times the International Standards for Drinking Water (PNA, 0.2 ppb).

The groundwater seepage sample from Site A contained arsenic and chromium which were roughly equivalent to the permissible criteria of the National Interim Primary Drinking Water Regulations.[57] The concentrations of the other elements in the water were either below the permissible criteria or not covered by the regulations. The method used was spark source mass spectrometry which did not include mercury and indium. Table 52 lists those elements which were found in sufficient quantities to be of some environmental concern.

TABLE 52. WATER POLLUTANTS OF ENVIRONMENTAL CONCERN IN GROUNDWATER SEEPAGE SITE A

		CONCENTRATION, ppm (mg/ℓ)	
Component	Seepage	MATE[a]	MEG[b]
Chromium	0.06	0.25	0.05,0.05[c]
Arsenic	0.05	0.05	0.01,0.05[c]
Nickel	0.02	0.01	0.0006
Iron	0.6		0.3[c]
Silver	0.005	0.005	0.005
Strontium	0.9	46	0.027
Zinc	0.08	0.1	0.02
Copper	0.02	0.05	0.01
Cobalt	0.002	0.25	0.0007
Manganese	0.3	0.1	0.02
Potassium	>10	30	0.075
Magnesium	>10	90	0.083
Lithium	0.04	0.33	0.0003

[a] Minimum Acute Toxic Effect, water

[b] Multimedia Environmental Goal, water

[c] Permissible Criteria

These concentrations were generally not substantially greater than minimum concentrations for acute toxic effects (MATE, a hazard to human health or to ecology induced by short term exposure to emissions). All of the concentration could not be considered compatible with Multimedia Environmental Goals (MEGs), necessary to prevent certain negative effects in the surrounding populations or ecosystems. A similar trend was observed in the groundwater of Company E, both under a slag dump (Table 53) and at the property boundary (Table 54). The concentrations of manganese and lithium are great enough to pose a potential environmental hazard under the slag dump, although they are not present in these concentrations at the property boundary well.

Several elements were apparently added to the stream as it flowed through Site E. Table 55 indicates that for each of the inorganic components which were present in concentrations sufficient to be of environmental concern, the concentration increased as it passed through the site. This was not true for each component concentration of the stream, since the organics, silicon, aluminum, and titanium decreased.

TABLE 53. WATER POLLUTANTS OF ENVIRONMENTAL CONCERN DETECTED IN A WELL AT THE BASE OF A SLAG DUMP SITE E

	CONCENTRATION, ppm (mg/ℓ)		
Component	Well Water	MATE[a]	MEG[b]
Strontium	1.0	46	0.027
Zinc	0.06	0.1	0.02,5.0[c]
Nickel	0.008	0.01	0.0006
Cobalt	0.004	0.25	0.7
Manganese	0.5	0.1	0.02
Potassium	>10	30	0.75
Aluminum	0.09	1	0.073
Magnesium	>10	90	0.083
Lithium	0.06	0.33	0.0003

[a] Minimum Acute Toxic Effect, water

[b] Multimedia Environmental Goal, water

[c] Permissible Criteria

TABLE 54. WATER POLLUTANTS OF ENVIRONMENTAL CONCERN AT THE PROPERTY BOUNDARY OF AN IRON AND STEEL LANDFILL SITE E

	CONCENTRATION, ppm (mg/ℓ)		
Component	Well Water	MATE[a]	MEG[b]
Strontium	0.06	46	0.027
Arsenic	0.02	0.05	0.01
Zinc	0.03	0.1	0.02,5.0[c]
Copper	0.01	0.05	0.01
Nickel	0.02	0.01	0.0006
Cobalt	0.006	0.25	0.7
Iron	0.7		0.3[c]
Titanium	0.1	0.82	0.083
Potassium	2	30	0.75
Aluminum	0.2	1	0.073
Magnesium	>10	90	0.083
Lithium	0.01	0.33	0.0003

[a] Minimum Acute Toxic Effect, water

[b] Multimedia Environmental Goal, water

[c] Permissible Criteria

TABLE 55. A COMPARISON OF POLLUTANT LEVELS IN A STREAM FLOWING THROUGH A LARGE IRON AND STEEL LANDFILL SITE E

Component	CONCENTRATION, ppm (mg/ℓ) Upstream	Downstream	MATE[a]	MEG[b]
Strontium	0.1	1	46	0.03
Selenium	≤ 0.008	≤ 0.007	0.025	0.005
Arsenic	≤ 0.003	≤ 0.02	0.05	0.01,0.05[c]
Nickel	≤ 0.01	≤ 0.05	0.01	0.0006
Cobalt	≤ 0.001	≤ 0.03	0.25	0.0007
Manganese	0.004	0.5	0.1	0.02,0.05[c]
Potassium	> 10	> 10	30	0.075
Aluminum	0.07	0.09	1	0.073
Magnesium	3	> 10	90	0.083
Lithium	0.009	0.6	0.33	0.0003

[a] Minimum Acute Toxic Effect, water

[b] Multimedia Environmental Goal, water

[c] Permissible Criteria

Table 56 summarizes the environmental pollutants of concern which were common to the five different water samples. Although the slag dump cannot be identified as the source of the groundwater pollution at the property boundary, those pollutants of environmental concern present in the groundwater were detected in significantly greater concentrations downstream than upstream. Most of the environmental pollutants of concern in Site A were also of environmental concern in Site E.

In summary, the groundwater did not meet the permissible criteria (Table 41) at any of the sites, and in many cases exceeded those criteria by one to two orders of magnitude. Special liners are required for the landfills so that the leachate may be collected if groundwater protection is required.

7.3.5 Descriptions of Selected Steel Industry Dump Sites

This section provides descriptions of selected steel industry dumps to provide insight into current disposal practices and the potential or proven adverse effects on the environment. It is important to note that RCRA requires the closing of sites classified as "open dumps" within five years of the promulgation of disposal criteria.

TABLE 56. WATER POLLUTANTS COMMON TO FIVE WATER SAMPLES FROM TWO IRON AND STEEL LANDFILL SITES

Component	CONCENTRATION, ppm (mg/ℓ)				
	Boundary Well Site E	Slag Dump Well Site E	Upstream Site E	Downstream Site E	Seepage Site A
Strontium	0.6	1.0	0.1	1	0.9
Arsenic	0.02	0.009	0.003	0.02	0.05
Nickel	0.02	0.008	0.01	0.05	0.02
Cobalt	0.006	0.004	0.001	0.03	0.002
Manganese	0.01	0.5	0.004	0.5	0.3
Potassium	2	>10	>10	>10	>10
Lithium	0.01	0.6	0.009	0.6	0.04

Plant A operates two sites comprising over 400 acres that have been in use for the past 40-50 years. The wastes dumped on these sites include iron and steelmaking slags, dusts, sludges, fly ash, waste acid, coke plant tars, oils and sludges, miscellaneous debris, and waste oils. A hydrogeologic survey contracted for by the plant revealed serious seepage and contamination and attributed the problem to random disposal techniques, mixing of wastes, runoff, and rainwater leaching. The study recommended the elimination of specific wastes, erosion control, containment structures downstream of the seepages, and closure by revegetation. According to the contractor, the potentially hazardous wastes which are currently deposited at the site are blast furnace sludge (cyanide), BOF slag and ESP dust (high pH), coal fines (ammonia, phenol), and tar decanter sludge (tar, phenol). The remaining life of the site was estimated as five years and the state agency plans to have the site closed as soon as an alternate site is approved.

Plant B is part of a specialty steel company that recently applied for and received a permit to operate a lined landfill for solid waste disposal. These wastes include incinerator ash, BOF sludge, acid rinse sludge, and hot rolling mill sludge. The landfill is to be prepared by removal of the topsoil, installation of a clay liner, and the addition of two feet of BOF slag as a leachate base. Drains and diversion channels will be constructed under the impoundment dike, and these gravel drainage trenches will be lined with 30 mil Hypalon plastic. The leachate drainage will be collected in a Hypalon-lined holding pond where a one day holding period will allow solids to settle and the supernatant (overflow) will be discharged to the river. Four groundwater monitoring wells will be installed and analyses will be reported quarterly; the holding pond will afford an additional monitoring point before the overflow is discharged. To meet future disposal needs, the holding pond may be filled in with slag and sludges with drainage to the next stage holding pond. The expected life of this site is 25 years.

Plant C has a state approved landfill which is an unlined facility that receives primarily steelmaking slag, but small quantities of oily mill sludge, pickle liquor sludge, water treatment sludge, and ESP dust are also dumped. The method of operation is to mix the dust and sludge and spread this mixture over the disposal area which is diked with slag. A hydrogeologic survey revealed that water infiltrates the soil down to impermeable bedrock, then moves downslope along the bedrock-soil interface. Surface water is collected in a stream and moves through the base of the site into a swamp. Two water observation wells are installed, one to monitor background water at a depth of 70 feet and one down gradient at a depth of 200 feet.

It is important to note that Plant C conducted tests to demonstrate to the state that slag effectively removed hazardous components in the sludge. The results showed that iron, cyanide, and some phenol were removed through multiple passages of water through a column containing five feet of slag and one inch of sludge. No phenol was detected in the leachate after five days, and it was presumed the phenolics were destroyed. The study also suggested that although some of the sludge is 50 percent oil, the oil was effectively controlled by the slag through some unknown mechanism. Their study also found that the sludge was impervious to water, and concluded that the horizontal layering of sludge on top of the slag would effectively prevent water passage through the sludge and greatly reduce leaching tendencies. The company plans to use the permitted area for solid waste disposal for the next 50 years.

An important environmental aspect of steel industry dump sites is the presence of deep mines in the major steel producing states of Pennsylvania, Ohio, Indiana, and Illinois. Exposed pyrite (FeS_2) in these mines oxidizes to sulfuric acid and can yield mine drainings with a pH less than 2 which can compound disposal monitoring problems. For example, Plant D has been dumping dusts, slag, sludges, and pickle liquor along a four mile stretch of their own property. Sludges are presently put into pits, but this procedure is being used without a state permit. The serious leaching problems that exist, are complicated by leaching coal refuse and acidic mine drainings in the area.

Company E is in the process of fulfilling state requirements to continue operation of a large dump site that has received steel wastes for about 75 years. Presently blast furnace slag, BOF sludge, EAF and OH dust, and fly ash are being deposited, and in the future, water treatment plant sludges will be landfilled. Plans include lined impoundment at an elevated location for these sludges which are composed primarily of oil, grease, and finely divided mill scale. Impoundment for other wastes were constructed in ravines by diking the lower ends of the ravines to prevent flow. A basin lined with bituminous material was constructed and used for ferro-manganese furnace fines.

An extensive hydrogeologic survey was conducted for this 500 acre site and revealed some of the following characteristics:

1. Several springs, swamps, and streams were identified.
2. Surface and deep mines and mining spoils were located. (The area underneath had been mined out and abandoned.)
3. The depth to groundwater ranged from 0 feet (springs) to 48.5 feet.
4. Major groundwater flow is through permeable sandstone and open joints.
5. Groundwater samples contained sulfate, aluminum, iron, phenol, manganese, and cyanide.

The life of this site is estimated at 50 years.

Plant F is currently disposing of wastes by filling in a lake bordering their property, and then using that area for plant expansion. Blast furnace slag is the major waste deposited, but miscellaneous dusts and sludges are mixed in and used for fill material. A permeable barrier of blast furnace slag with steel supports and concrete cap extends into the lake to mark the future limits of the fill area. The company plans to use the 300 acres of lake between the fill and barrier as their solid waste disposal site for the next 20 years. This procedure is not environmentally sound based on RCRA criteria for solid waste disposal, since the criteria require the prevention of direct discharges into surface waters of unchanneled leachate seepage, when possible.

7.4 IMPACT OF SECTION 4004 RCRA CRITERIA

The Resource Conservation and Recovery Act provides for the promulgation of regulations for the criteria for determining which facilities shall be classified as sanitary landfills and which shall be classified as open dumps. The general current practice in the iron and steel industry is the dumping of wastes in unlined sites. The major impact of Section 4004 is to require the disposer to control the leachate migrating toward the groundwater.

All steel plant waste, with the possible exception of bricks, rubble, and certain trash items are anticipated to have leachate which is unfit for human consumption. This causes concern for the effect of leachate on the groundwater. Contaminants such as oil and grease, dissolved solids, fluorine, chromium, manganese, lead, iron, phenol, cyanide, cadmium, zinc, and mercury have been identified in the extract of some of the various iron and steel wastes at concentrations greater than the permissible criteria.

Although most steel plant wastes are not classified as hazardous, available leachate and/or water extraction test data have shown the extract to be unfit for human consumption. In view of these facts and in evaluation of environmental endangerment, a lined landfill could be required for these wastes. However, hazardous wastes are specifically excluded from landfill under Section 4004, since they are regulated under Subtitle C of RCRA. A major economic impact may result if contaminants must be removed from the collected leachate. The leachate disposal method assumed for nonhazardous wastes is controlled discharge to waterways or recycle back through the landfill.

Discarded steelmaking slag would need liners because of the high pH of the water extract, the dissolved solids in the extract, and the organic compounds as well as inorganic elements. However, the slag does not require lined landfilling if it is used as a salable product, for resource recovery, under Case 2 of the proposed rules. Since steelmaking slags are a major landfilled waste, two calculations were performed on the economic impact of the proposed criteria with and without the required lined landfilling of steel slag.

The impact of Section 4004 on the iron and steel industry was calculated assuming the following: the criteria requires the lined landfilling of certain wastes, the removal of the leachate resulting from rainfall on these wastes, and the controlled discharge of the water which is collected. Therefore, the cost of the criteria would be the cost of converting an existing landfill into an area for the collection and removal of leachate and would require a substantial capital investment. The criteria do not specifically require changes in current solid waste disposal practices such as the transportation of wastes, employment of landfill personnel, or purchase of land for waste disposal. It should be pointed out that the costs of Section 4004 do not include those costs incurred as a result of hazardous waste disposal, which may be more expensive than for nonhazardous wastes.

The estimated annual capital cost for lining nonhazardous waste landfills is $6.9 million (Table 57). The cost of a lined landfill for steel slag disposal is approximately twice that of nonslag nonhazardous waste disposal. Although some economies of scale are achieved with increasing waste disposal volume, when steel slag is placed in a lined landfill, the overall cost is still three times as high. The estimated cost is relatively low for two major reasons. One primary consideration is that only the cost of converting a potential landfill site to a lined landfill was considered. The second major factor is that the majority of iron and steel wastes are currently either recycled, sold, or used in a manner consistent with the objectives of RCRA.

TABLE 57. SUMMARY OF ESTIMATED 4004 CRITERIA COSTS

Enforcement	Annual Capital Cost ($ Millions)	% Current Environmental Costs	% Future Environmental Costs	% of Sales	% of Current Disposal Costs
A-Steel Slags Excluded	6.9	0.63	0.2	0.01	12
B-Steel Slags Included	21.1	1.9	0.6	0.04	38

When the estimated implementation costs of Section 4004 are compared with other costs in the industry, it is apparent that those costs would not be a significant factor in the compliance ability of the industry. This cost is also relatively low in comparison to either the current or projected environmental costs and extremely small when compared to the percent of sales. On this basis it is expected that the criteria will have little impact on either the cost of products or the economics of production.

Current disposal costs are estimated for 30 million tonnes of nonhazardous waste at an average cost of $1.90 per tonne or $58 million. As Table 57 shows, this represents a small fraction of current and future environmental costs. Current annual environmental operating costs were estimated as $8 per ton of steel, including the cost of air and water pollution control.[59] The long term environmental costs, including disposal of nonhazardous solid waste, are estimated as $3,620 million per year.[11] This estimate is consistent with the Council on Wage and Price Stability's estimate of $18-33 per ton.[59]

Section 4004 will, however, have a major impact on the disposal practices used by the industry and substantially increase the cost of present land disposal systems. It is estimated that the capital costs for developing leachate collection facilities alone will double the disposal costs of those wastes placed in lined landfills.

7.4.1 Landfill Site Monitoring for Enforcement of Groundwater Standards

The cost of enforcement monitoring for groundwater contamination will range from several thousand dollars to several tens of thousands of dollars,[50] and will be higher than for assessment monitoring. One of the reasons for this is that quantitative data will be necessary regarding leachate contamination at a landfill site. There must be sufficient evidence to prove beyond any reasonable doubt that the contamination exceeds applicable standards and that this excess is caused by the land disposal site. This wide range of possible costs is due to the differences in site conditions and state laws. Monitoring for zero discharge laws requires sampling devices immediately adjacent to the downgradient landfill edge or beneath the site whereas more costly monitoring would be involved in cases concerning property line laws. In these cases, several monitoring wells at various distances and depths downgradient as well as comprehensive surveys, especially depth to groundwater, will directly affect the installation costs of sampling devices.

The proposed EPA rules state that as long as leachate may enter groundwater in such quantities and concentrations that the groundwater quality may be endangered, monitoring of groundwater, prediction of leachate migration, and a current and acceptable contingency plan for corrective action are required.[53] The prediction of leachate migration can be determined only by interpretative monitoring which differs from detective monitoring which only establishes the presence or absence of contaminants.[50] Interpretative monitoring determines the extent of damage by leachate and prescribes remedial action.

A major limitation to monitoring and characterizing the nature of the groundwater pollution lies in the nature of the plume itself. The pollutants which leach out in different parts of the landfill may have different impacts on the groundwater quality. Due to the nature of the formation of the plume, there is severely limited radial mixing. Thus, there may be a wide range of unpredictable variations in contaminant concentrations within a plume of leachate-enriched groundwater.

A number of factors serve to complicate the prediction of leachate migration. Wide variations have been observed in leachate concentrations over short distances and time periods and sampling at additional points implies the installation of additional monitoring wells. Before installation can take place, however, determination of the flow rate and groundwater direction are prerequisites. Because groundwater flow rates are slow, data must be collected over long periods of time in order to perform a comprehensive analysis of the landfill. Conditions such as fractured rock are so unpredictable as to frustrate an intensive monitoring effort. As a result, interpretative monitoring which determines the extent of damage and prescribes remedial action is not considered practical for every disposal facility.[50] Detective monitoring, however, can be useful to establish the presence of contaminants. The technique will establish the need for additional monitoring if necessary and a plan for remedial action.

A minimally acceptable monitoring well network should consist of the following:[50] one line of three wells downgradient from the landfills penetrating the entire saturated thickness of the aquifer, one well immediately adjacent to the downgradient edge of the field area screened so that it intercepts the water table, and one well completed in an area upgradient from the landfill so that it will not be affected by potential leachate migration. Every effort should be made to have a minimum of five wells at each landfill and no less than one downgradient well for every 76 meters of landfill frontage.[50]

Even if wells are sited according to the background information described here there is a high probability that one or more of them will not intercept the plume of leachate-enriched groundwater due to the anisotropic nature of the aquifer material. Also, the operation of the landfill can significantly influence concentrations of pollutants observed in the monitoring wells since the location of a pollutant in the landfill determines the location of the leachate from that waste in the overall leachate plume. Depending upon the hydrogeological nature of the landfill site, the leachate plume may be confined to the landfill site or it may travel long distances. Also the plume may divide into multiples, move into different aquifers or reverse its direction.[50] If the monitoring program is to be effective, it must account for all possible leachate movement.

When monitoring is to be used as an early warning system, sampling in the zone of aeration is desirable. This type of monitoring is most appropriately done directly beneath the landfill where the leachate is migrating downward to the water table. The devices to be used should be in place before construction of the impoundment facility thus avoiding the possibility of creating other potential leakage sources by drilling through the landfill. Pressure vacuum lysimeters are used to monitor the zone of aeration. Some of the advantages of this device are that it is inexpensive, reliable, and standard water analyses can be made.[50]

Table 58 presents various cost factors for surveying and monitoring a typical two acre landfill site. Although the cost of a hydrogeological survey would be dependent upon location, typical costs might be $13,000 per site. This cost does not include the cost of locating a suitable site. The placement of three five-well clusters with a 1.5 meter screen in each well and four lysimeters in the zone of aeration under the landfill is estimated to cost an

TABLE 58. COST FACTORS FOR SURVEYING AND MONITORING A TYPICAL TWO ACRE SITE

	Cost ($)
Location, mapping, survey[a]	2,000
Soil study[a]	1,400
Geology (4 borings)[a]	4,200
Hydrology (4 wells)[a]	3,800
Flooding, Climatology[a]	600
Discharge to groundwater survey[a] (6 sets of analyses)	1,200
Monitoring Wells (3) 5 well cluster 1.5 meter screen[b]	9,200
Lysimeters (4)[c] installed under the landfill	1,300
TOTAL	24,300

[a] Green Engineering, Pittsburgh, PA, 1978[60]

[b] EPA Procedures Manual, inflated at 10 percent per year to 1978[50]

[c] RTI estimate, 1978

additional $10,000. This brings the total estimated cost for surveying and monitoring to $24,300. An additional $3,000 is estimated to be required annually for quarterly water analyses. This cost as well as the expense of obtaining the samples to be analyzed should be considered an operating expense. Therefore, the total cost to the industry for Section 4004 would be the capital plus operating costs.

The cost of the hydrogeological survey and well installation is a capital expense and is included in the cost of the facility. Twenty percent of the excavation and grading costs is allocated for the survey and wells. For the model plant of 2.5 million tonnes of steel per year, the 20 percent survey allocation would be $27,000 for a landfill holding one year of waste production. For an average sized EAF plant of 600,000 tons per year, the development of a 3 year disposal facility would result in an allocation of $24,000. Therefore, this 20 percent estimates the survey and monitoring well expenses and represents about 20 cents per cubic meter of solid waste.

Within the accuracy of the expected capital costs, the estimated $3,000 annual analytical costs are not expected to be a significant contribution and, therefore, are not included in the economic analysis. The analytical costs become a significant aspect of overall landfill costs if the key indicators demonstrate a potential problem with groundwater quality. If this is the case, then more extensive testing would be required and its cost would be dependent upon state regulations. With iron and steel wastes, some of the leachate constituents of interest are as follows:

1. Lead
2. Chromium
3. Cadmium
4. Oil and Grease
5. Polycyclic Organic Materials
6. Benzo(a)pyrene
7. Cyanide
8. Phenols
9. Mercury

These constituents are some of those found in iron and steel wastes; the National Interim Primary Drinking Water Standards, however, do not as yet include polycyclic organic materials or benzo(a)pyrene.

7.4.2 Model Facility

The cost of lining solid waste landfills has been developed by considering the development costs for a model facility. The overall operating costs of a landfill include land, labor, earthmoving equipment and trucks, lining, groundwater monitoring, as well as other factors.

A major cost component is the development of those lined landfill facilities which will be required to eliminate leachate endangerment to the environment. The approach taken has been to isolate the actual costs of converting an existing landfill into a site providing for the collection and removal of leachate. Figure 20 is a sketch of a model facility with leachate control. The facility, however, is not to be confused with the recommended or required method of leachate control and is presented only to provide an order of magnitude estimate of lined landfill costs.

The model facility is lined with 0.6 meters of clay and sealed with bentonite. A drainage system is installed in the bottom of the facility and

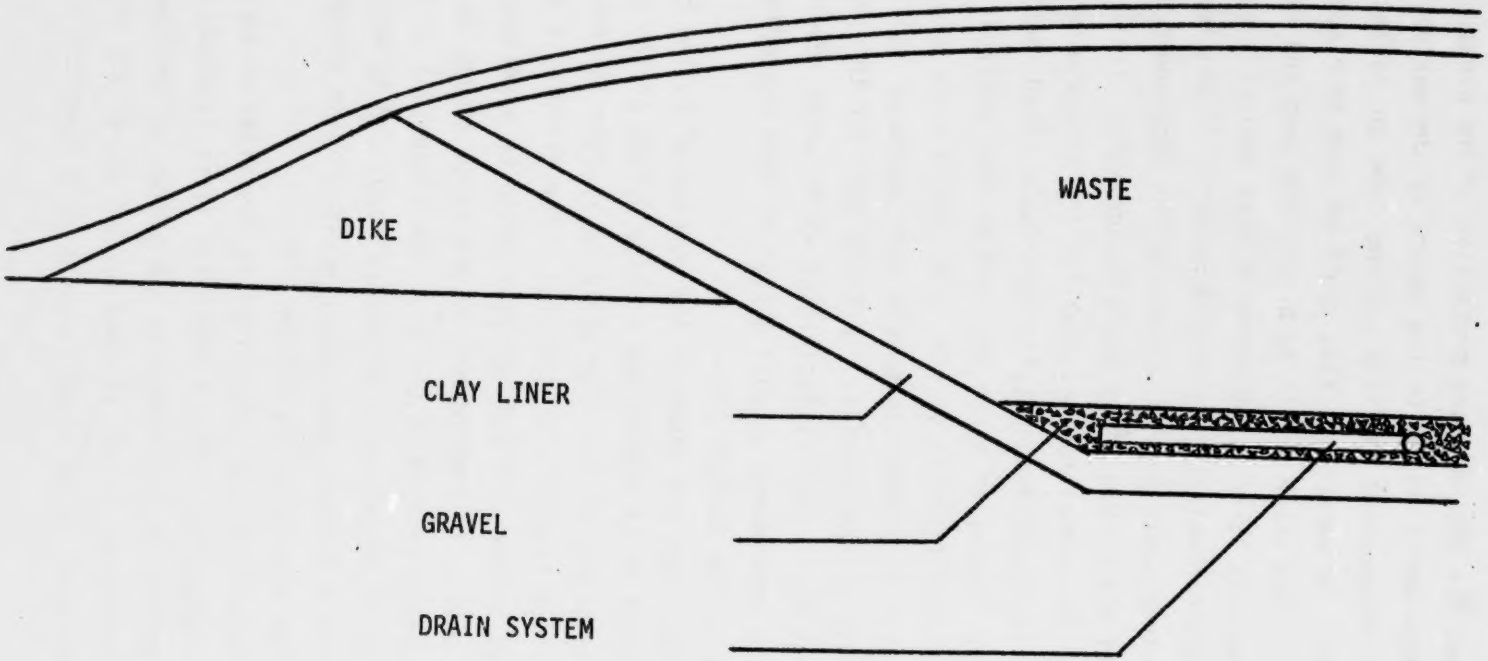


Figure 20. Diagram of a sanitary landfill with leachate collection.

covered with gravel for drainage and protection of the pipes. The type of drainage system used would depend on the nature of the wastes. For example, water entering an impoundment facility storing coke tar collects on the surface of the tar. In many cases slag could be used in place of gravel, reducing the cost. The water drains to a concrete sump and is pumped out.

Leachate treatment is not considered in this analysis, only controlled discharge in an environmentally acceptable manner. If the leachate were hazardous, the wastes would not be subject to the proposed criteria but would be subject to Subtitle C "Hazardous Waste Management." It is both conceivable and probable that the annual cost of treating the leachate may exceed the annual cost of constructing an environmentally acceptable lined landfill facility.

In the Figure, excavated earth was used to form peripheral dikes, increasing the potential landfill volume. The leachate collection drains were assumed to be placed at 2 meter intervals with two major collection drains crossing the length of the landfill. A fixed cost for the sump and pump was established as $4,340. Landfill facilities which would require a more effective pump are considered to cost enough so that upgrading of the pump would add little to the overall cost.

The excavation cost was based on the concept of moving earth from the trench to form dikes which double the storage volume of the trench and have a 26.5° slope. The height of the dike would be as deep as the excavation trench for the large volume landfills of interest. For example, a small EAF plant producing 200,000 tonnes of steel per year could be expected to generate 2,500 m^3 of waste per year. An impoundment volume large enough to store 10 years supply of waste would contain 25,000 m^3. The dimensions of the impoundment facility could be 10 meters deep, 80 meters long, and 40 meters wide. Excavated earth from a 5 meter deep trench would provide enough material to build a 26.6° dike and cover the filled site.

After the trench is dug, clay liner is installed at an estimated $2 per cubic meter and compacted. Then a bentonite layer is mixed with the surface of the clay. The piping is positioned in the bottom of the trench and covered with gravel. Additional gravel is used on one end of the trench. With the development of the model lined landfill costs as a function of the dimensions of the landfill, the costs were calculated for a variety of landfill sizes. The shape of the landfills were selected as 4:2:0.5, the length to width to depth ratio. Eight different sized landfills were selected for this same shape. The results are presented in Table 59.

TABLE 59. THE COST OF LANDFILL LINERS FOR VARIOUS SIZED LANDFILLS (L:W:D) = (4:2:0.5)

Volume Cubic Meters	Cost ($)	Cost/Volume ($/Cubic Meter)
256	11,500	45.0
864	15,900	18.4
4,000	31,700	7.91
13,500	67,600	5.0
32,000	126,000	3.93
108,000	328,000	3.04
500,000	1,208,000	2.41
1,688,000	3,584,000	2.12

The cost of the larger landfill is expected to be somewhat higher than the model indicates due to the somewhat excessive depths obtained with a LWD ratio of 4:2:0.5. The disposal of dusts and sludges could be impractical in depths of 25 meters unless special techniques were used. Steel slags could be used as intermediate cell cover, for example.

Table 60 presents several estimates for operating a facility with leachate impoundment. The cost of impounding metallurgical solid wastes was estimated by Agarwal, et al.[61] A square pond was formed on level land by earthen dikes and PVC sheet. The expenses for developing a storage pond in a canyon or ravine surrounded by a large earthen dam were expected to be substantially less than costs for level land. The typical integrated iron and steel plant generates 36,000 metric tons of nonhazardous solid wastes. Bricks and rubble, as well as slag are not considered in the landfilled wastes. A 180,000 m^3 impoundment lagoon that provides for 5 years' waste production was estimated as costing $250,000. The annual cost of financing the project at 12 percent

TABLE 60. LANDFILL COSTS FOR NONHAZARDOUS WASTE LEACHATE COLLECTION AND REMOVAL. (Generated in the Model Plant, dollars per metric ton, 2.5 Megatonne production, specific gravity of waste-2.0)

Reference	$/Metric Ton
Calspan, operation costs[a]	7.5
Arthur D. Little, Inc., operation costs[b]	10.0
RTI, impoundment costs only[c]	1.9
RTI, pond impoundment costs only	1.46
Calspan, impoundment costs only[d]	1.6

[a] Annual impoundment and waste segregation is considered, as well as the cost of hauling, labor, etc.

[b] Based on contract hauling costs.

[c] Cost of converting an existing site for sanitary landfill leachate collection and removal.

[d] Difference in landfill cost due to impoundment, excavation excluded.

interest is $69,000. The cost per metric ton, with a specific gravity of 2.0, is $0.96. This cost is based on 1973 dollars and was estimated as $1.46 per tonne in 1977 dollars using a 10 percent inflation rate. The cost estimate for the lagoon is provided for comparison with the cost of the model facility.

RTI's estimate of the lined landfills costs for the model plant was based on the estimated cost of a model facility (Table 61). Clay is assumed to be available on site, and the costs of the other components include transportation costs. Bentonite is used in addition to the clay to provide additional protection. Special earth additives may be required to reduce the permeability of the compacted earth in many sites. The component costs are expected to be site specific because of transportation costs and local availability.

The cost per volume as a function of volume was used to prepare Figure 21. Although the economics are expected to be very sensitive to the volume, it is relatively insensitive for the large landfill volumes.

The expense of developing a lined sanitary landfill is a capital expense. However, if a landfill facility is developed each year, it could be considered

TABLE 61. COST FACTORS FOR THE MODEL IMPOUNDMENT FACILITY

1.	Excavation[a]	$2(LWD/2)$[e]
2.	Grading[a]	$0.4\ (LW-2\ DW-2\ DL+D^2)$
3.	Survey and Testing[a]	20% of (1) + (2)
4.	Clay Base[b]	$(2.0)(0.61)(LW+2.47\ DW+2.47\ DL+4D^2)$
5.	Bentonite Surface Layer[a,c]	$1.8\ (LW+2.47\ WD+2.47\ DL+4D^2)$
6.	Drains[a]	$6.00\ (2L-4D+0.5\ LW+2D^2-LD-WD)$
7.	Gravel[d]	$9.10\ (0.61\ LW+0.15\ WD-1.22\ DL+2.44D^2)$
8.	Bentonite Cover[a,c]	$1.8\ (LW+2DW+2DL+4D^2)$
9.	Earth Cover[b]	$0.4\ (LW+2DW+2DL+4D^2)$
10.	Concrete Sump	2,340
11.	Pump	2,000
12.	Electrical, pump piping, etc.	2,000
13.	Contingency	30% of the above

[a] Calspan[16]

[b] RTI

[c] EPA[62]

[d] Building Construction Cost Data 1978[63]

[e] L,W,D are the average length, width, and depth in meters.

an annual cost. If a facility is built and financed which can be used for the disposal of 10 years waste, then the annual cost is the cost of the repayment of principal plus interest. This method permits the producers of relatively small volumes of waste to take advantage of some of the economies of scale evident in Figure 21. A disadvantage to lining a large area is that a plant is paying for disposal volume which is not used in the immediate future. Thus, there is a "trade-off" between the additional cost of a small facility and the additional interest charges from a large facility. Figure 22 presents optimization curves for three different sizes of plants: a small (1,000 m^3 of waste per year waste), medium (10,000 m^3 of waste per year), and large steel plant (50,000 m^3 per year). The small plant has an optimum landfill size equivalent to 5-10 years waste production but the medium and large steel plants economically operate with landfills sized for 2-5 years production. The values obtained for the optimum costs in Figure 22 are plotted in Figure 23. This relationship is used to develop the industry's cost for compliance with RCRA Section 4004.

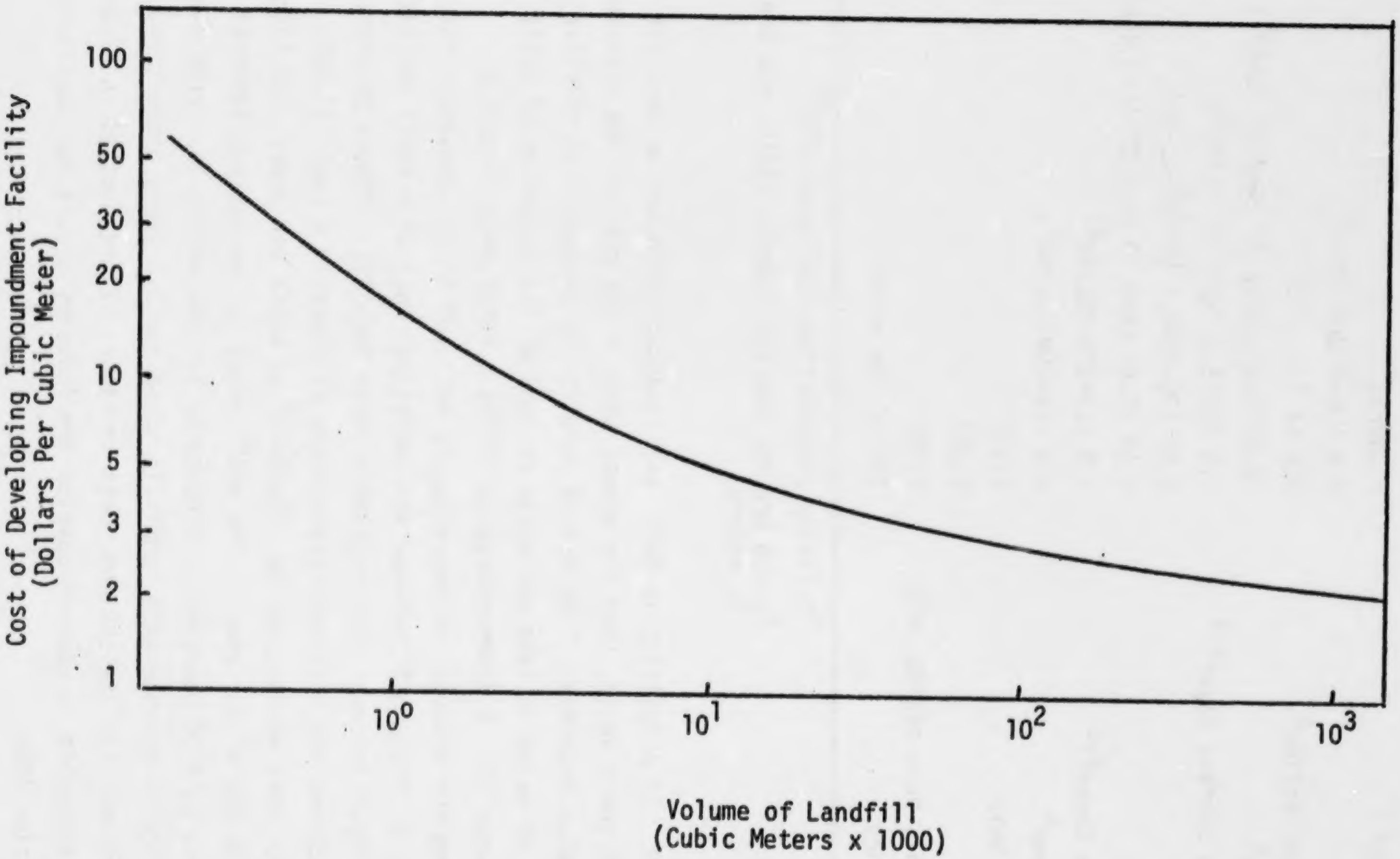


Figure 21. Cost factors for various landfill sizes.

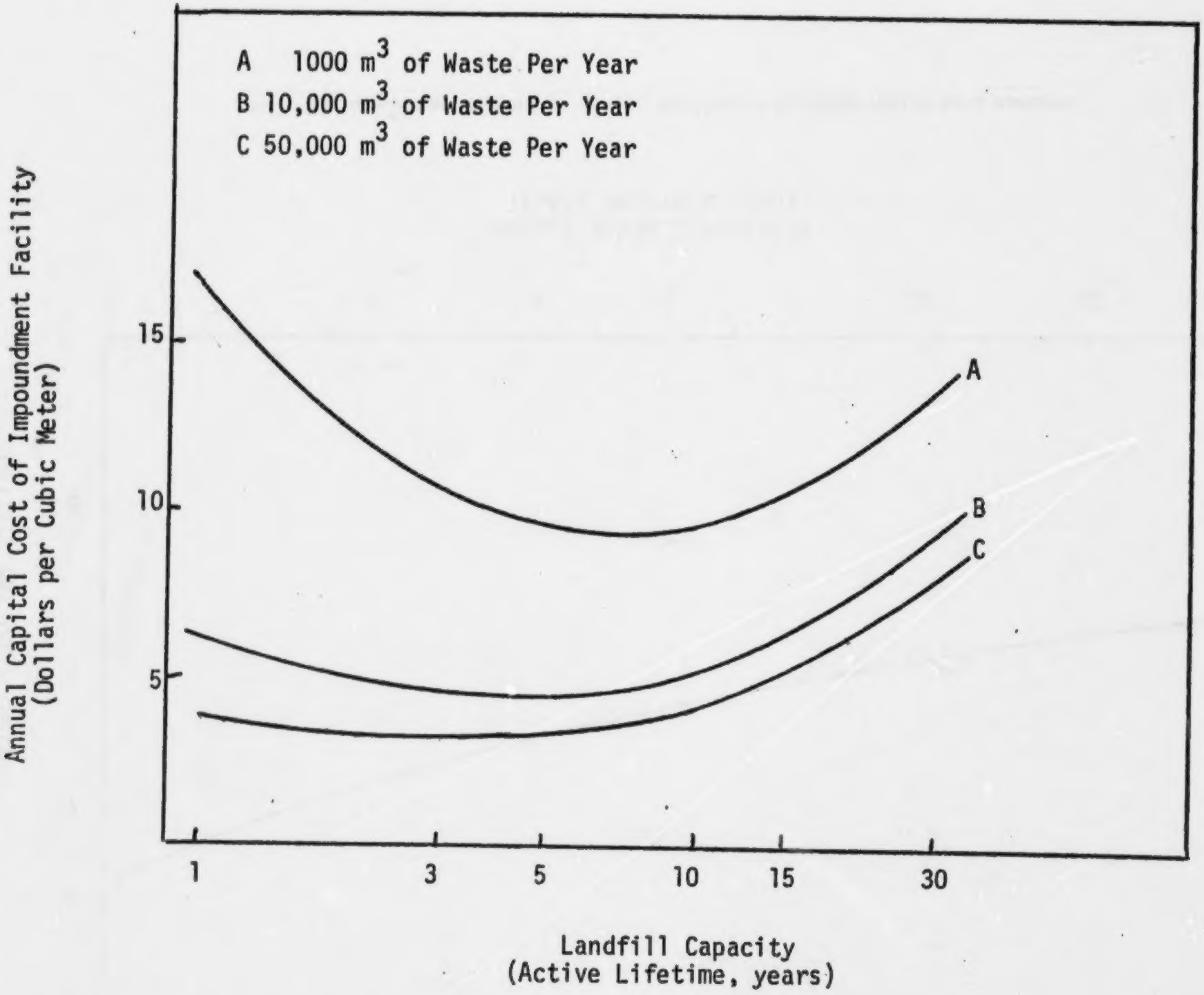


Figure 22. The cost of waste impoundment as a function of the number of years of landfill capacity for three rates of waste generation.

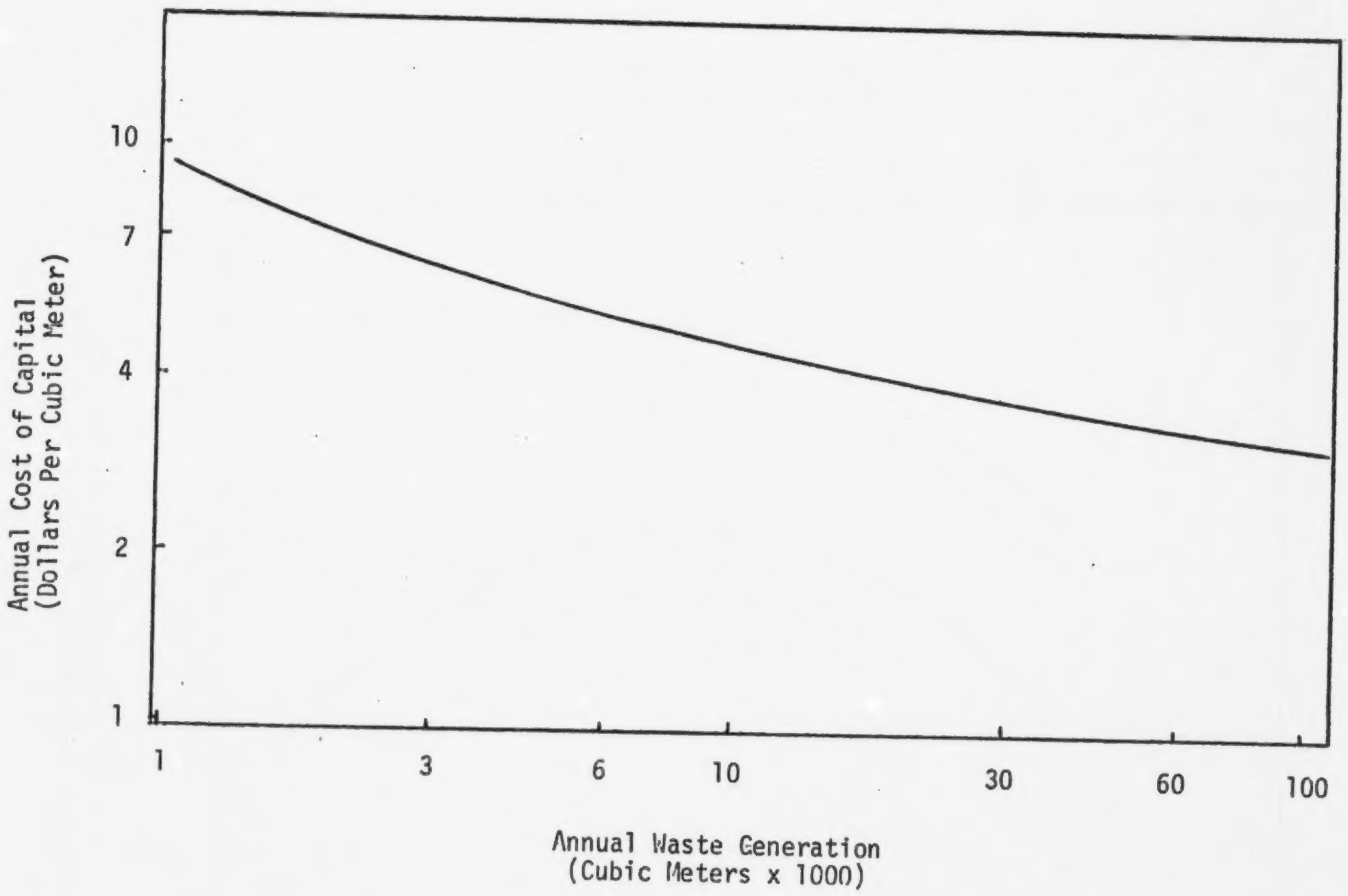


Figure 23. Annual costs of capital for optimum sized landfills for various rates of waste generation.

The steel industry is divided into two types of plants, (1) facilities comprised of relatively small EAF's and (2) facilities containing large blast furnaces, BOF's, and open hearth furnace plants. For each of these types, the total production was divided into tenths and a cost figure, using Figures 21 and 23, was developed for a typical plant in each production division. Summation of the individual costs provided the estimate of the cost to the industry. Table 62 summarizes the costs for the segments of the two plant types.

The annual capital cost for converting landfills from open dumps to lined landfill sites is estimated to be $6.92 million. This represents 0.014 percent of the selling price of steel (6 company average, $397.77 per ton in 1977). This amount is not expected to have a significant economic impact on the steel industry; however, this impact could be severe for contract haulers, especially considering the required capital investments in Table 59.

Table 63 summarizes the cost of capital needed to develop larger sanitary landfill sites for slag. A typical integrated iron and steel plant would require approximately $400,000 per year to line steelmaking slag and other nonhazardous wastes landfills. This figure represents a cost of $0.16 per ton of steel. Tables 64 and 65 summarize landfill facility costs in view of the current practice of discarding half of the steelmaking slag and the annual landfill cost when this slag is excluded.

The estimated annual capital cost for steelmaking slag that is currently landfilled is $14 million, increasing the annual capital cost of landfill facilities threefold. The estimated annual cost for landfilling all wastes, excluding bricks, rubble, trash and blast furnace slag is $21 million. This figure represents 0.042 percent of the selling price of steel. If steelmaking slag is discarded rather than used as a product, then it should be disposed of in a sanitary landfill.

The economic impact is also contingent upon the regulations developed to control hazardous and nonhazardous wastes. For example, a state may declare an aquifer under a nonhazardous waste landfill for use other than as a drinking water supply per Section 257.3-3(b) (1) of RCRA. In this case, there would be

TABLE 62. CAPITAL COST TO LINE LANDFILLS FOR VARIOUS PRODUCTION SEGMENTS OF THE IRON AND STEEL INDUSTRY.* (The Industry is divided into tenths by the amount of steel produced for two types of plants.)

Cumulative Fraction of Production	EAF Only		Plants with BF, BOF, OH	
	Plant Size (1000 Tonne of Steel/Yr)	Landfill $\$/m^3$	Plant Size (1000 Tonne of Steel/Yr)	Landfill $\$/m^3$
0.1	0-160	8.4	0-1600	4.2
0.2	160-250	6.4	1600-2300	4.0
0.3	250-350	5.8	2300-2500	3.8
0.4	350-450	5.4	2500-3000	3.7
0.5	450-600	5.1	3000-3500	3.6
0.6	600-750	4.8	3500-4000	3.5
0.7	750-1000	4.6	4000-4750	3.4
0.8	1000-1200	4.4	4750-5700	3.3
0.9	1200-1500	4.3	5700-7200	3.2
1.0	1500-	4.2	7200-	3.1
Average Costs ($\$/m^3$)		5.34		3.58
Average Costs (\$/tonne) (S.G. = 2.0)		2.67		1.79

*Steelmaking Slags Excluded

TABLE 63. CAPITAL COST TO LINE LANDFILLS FOR VARIOUS PRODUCTION SEGMENTS OF THE IRON AND STEEL INDUSTRY.* (The Industry is divided into tenths by the amount of steel produced for two types of plants.)

	EAF ONLY		Plants with BF, BOF, OH	
Cumulative Fraction of Production	Plant Size (1000 Tonne of Steel/Yr)	Landfill $/m^3	Plant Size (1000 Tonne of Steel/Yr)	Landfill $/m^3
0.1	0-160	5.1	0-1600	3.3
0.2	160-250	4.4	1600-2300	3.1
0.3	250-350	4.2	2300-2500	2.9
0.4	350-450	3.9	2500-3000	2.8
0.5	450-600	3.8	3000-3500	2.7
0.6	600-750	3.6	3500-4000	2.6
0.7	750-1000	3.4	4000-4750	2.5
0.8	1000-1200	3.3	4750-5700	2.5
0.9	1200-1500	3.2	5700-7200	2.5
1.0	1500-	3.1	7200-	2.4
Average Costs ($/m^3)		3.84		2.74
Average Costs ($/tonne) (S.G. = 2.0)		1.93		1.37

*Steelmaking Slags Included

TABLE 64. A SUMMARY OF THE YEARLY CAPITAL COST TO CONSTRUCT LINED LANDFILL FACILITIES FOR IRON AND STEEL WASTES.* (Steelmaking Slags Excluded.)

	Quantity Steel (10^6 Mg/Yr)	Quantity Waste (10^6 Mg/Yr)	Costs ($/Mg)	Costs ($ x 10^6)
EAF Only Plants	24.2	0.621	2.67	1.66
OH, BOF Plants	100.8	2.94	1.78	5.26
All Iron and Plants	125.0	3.55	1.94	6.92

*Principal + financing costs

TABLE 65. A SUMMARY OF THE YEARLY CAPITAL COSTS TO CONSTRUCT LINED LANDFILL FACILITIES FOR IRON AND STEEL WASTES.* (Steelmaking Slags Included.)

	Quantity Steel (10^6 Mg/Yr)	Quantity Waste (10^6 Mg/Yr)	Costs ($/Mg)	Costs ($ x 10^6)
EAF Only Plants	24.2	3.171	1.93	6.12
OH, BOF Plants	100.8	10.94	1.37	15.0
All Iron and Steel Plants	125.0	14.11	1.50	21.1

*Principal + financing costs

no economic impact from Section 4004. However, another state could require an artificial liner, multiple liners for contingency purposes, monitoring of groundwater movement near the site, and leachate treatment facilities. These requirements could pose a significant impact, particularly on a smaller plant.

7.5 ALTERNATIVE DISPOSAL PRACTICES FOR THE IRON AND STEEL INDUSTRY

The Resource Conservation and Recovery Act provides for the promulgation of regulatory criteria for determining which facilities shall be classified as sanitary landfills and which shall be classified as open dumps. Any management practice which constitutes the open dumping of solid waste is prohibited, and all open dumps will be either closed or upgraded to meet the criteria of Section 4004 with an acceptable timetable for compliance.[52] The criteria provide that a facility is classified as a sanitary landfill and not an open dump only if there is no reasonable probability of adverse effects on health safety, or the environment, and if it is located, designated, constructed, operated, completed, and maintained as prescribed by the criteria.[52,53]

The major adverse effect is groundwater contamination. The law provides protection through the requirements that the landfill not make the water unfit for human consumption, that the groundwater user does not need to increase water treatment before use, and that it is unnecessary for a future user to use more extensive water treatment than would otherwise be necessary.[53]

One method of preventing groundwater endangerment is to use the site's natural hydrogeologic conditions and soil attenuation mechanisms. However, soil attenuation alone may not provide definite assurance of the quality of the leachate plume from iron and steel wastes. The other technique for preventing endangerment of the groundwater is the collection of leachate through the use of artificial liners where the leachate is removed, recirculated, or treated as appropriate.[53]

A state may designate a groundwater source for use other than as a human drinking water supply if it is impractical for use as such or if alternative drinking water supplies are available.[53] Under these circumstances, the waters of an adjacent state or county must not be endangered by the landfill. When a groundwater source is designated for another use, the state may specify what groundwater quality must be obtained at the disposal site's property boundary. This special designation could be useful in situations where a state wishes to maintain an existing landfill, when artificial liners would serve no useful purpose, or in site specific cases when the nature of the waste and the landfill location is neither a danger to the environment nor expected to contaminate wells.

One type of special use of iron and steel wastes is land modification and improvement by selected landfilling. There are examples of iron and steel plants increasing their size through such operations. States could permit the regulated use of these wastes for land reclamation by special groundwater source designations.

7.5.1 Sole Source Aquifers

The location of sole source aquifers must be considered when examining alternative disposal practices. Section 1424(e) of the 1974 Safe Drinking Water Act makes it possible for EPA to designate areas which are principally dependent upon an aquifer for drinking water supply. Aquifers are geological formations which yield significant quantities of water to wells or springs. They are replenished through recharge zones which permit rainfall and surface runoff to enter the aquifer. In the recharge zone, the aquifer is especially sensitive to contamination from a disposal site. Disposal sites should not be located in the recharge zones of sole source aquifers when feasible alternatives exist. The feasibility of the alternative site is to be determined by technological and economic factors. When a landfill is to be permitted in the recharge zone of the sole source aquifer, special precautions must be taken so that it is located, designed, constructed, operated, maintained, and monitored to prevent endangerment to the aquifer.

7.5.2 Waste Separation

The separation of hazardous and nonhazardous wastes should also be considered when evaluating alternative disposal practices. The major effect of RCRA on current iron and steel mill waste disposal practices is the isolation of hazardous waste material. These wastes, are not to be placed in a sanitary landfill but in special lined hazardous waste landfills. Removing the hazardous materials from the sanitary landfill reduces significantly the probability of environmental damage. The leachate which is collected from the nonhazardous waste material is less than 10 times the drinking water standards for many of the criteria pollutants. Although this level of environmental pollutants does not guarantee the controlled discharge into streams under an NDPES permit, in some cases the dilution factor would be sufficiently great for the collected leachate to be directly discharged into surface water systems.

The hazardous waste materials produced by iron and steel mills include some of the coke plant wastes, ferromanganese blast furnace dust and sludge, EAF dust and sludge, and selected steel finishing wastes. The steel plant wastes published in the proposed hazardous waste regulations are presented in Table 66.

TABLE 66. OFFICE OF SOLID WASTE LIST OF HAZARDOUS IRON AND STEEL WASTES

Coking	Decanter tank tar, toxic, organic. Decanter tank pitch sludge, toxic, organic. Oleum wash waste, corrosive. Caustic neutralization waste, corrosive. Ammonia still lime sludge, toxic.
Ironmaking	Ferromanganese blast furnace dust, toxic, reactive. Ferromanganese blast furnace sludge, toxic. EAF dust, toxic. EAF sludge, toxic.
Steel Finishing	Alkaline cleaning waste, corrosive. Waste pickle liquor, corrosive. Cyanide bearing wastes from electrolytic coating, toxic. Chromate and dichromate wastes from chemical treatment, toxic.

A hazardous waste is hazardous because of its inherent characteristics. Current EPA characteristics for the classification of hazardous wastes are ignitability, corrosivity, reactivity, and toxicity. Additional waste may be classified as hazardous when other criteria, such as mutagenicity, are developed.

7.5.3 Artificial Liners

Leachate is formed by water infiltrating a landfilled waste. The leachate migrates through the soils under the solid waste and is attenuated by ionic change, filtration, adsorption, complexing, precipitation, and biogradation.[64] If the voids in the soil are filled with water, the leachate moves to the groundwater where there is little dilution unless a natural geologic mixing basin exists. Natural purification processes have limited ability to remove contaminants because of the limited number of adsorptive sites and exchangeable ions. Natural leachate treatment is also time dependent; lower flowrates are more efficiently attenuated. A site's hydrology is extremely important since it determines, to a large extent, leachate formation and dispersion. Soil permeability is a measure of the rate at which water can move through it. Coarse soils such as gravel and sand are generally more permeable than fine grained soils such as silts and clay, but not necessarily. For example, small amounts of fines in sand and cracks in clay can reverse the respective permeability.[64]

An artificial liner may be employed to control the leachate movement. One of the most commonly used is a well-compacted clay soil, one to three feet thick kept moist to prevent cracking.[64] If sufficient clay soil is not available locally, natural clay additives may be mixed with it. The use of additives requires testing to determine the optimum type and amounts. For cohesionless soils, or situations where the necessary degree of compaction is not practical, liners can be constructed of asphalt or polymer membranes.

Polymer membranes have not generally been used for solid waste disposal sites, therefore, limited data are available regarding long term effectiveness. The membrane covering should consist of a fine textured material which can be placed with a dragline, conveyor, or truck. Heavy equipment cannot move over the liners until they are protected with six to eight inches of cover.[65] A side slope of at least three to one is necessary to assure stability of the cover materal on the slope. Before the liner is put in place, the slopes should be graded and any debris that might damage the membrane should be either removed or covered with a fine textured soil.[65] The liner should cover the sides of the basin to reduce the potential for lateral leachate movement. Perforated pipes should be placed along the center lines of the disposal basin and covered wth granular materials such as coarse sand or gravel. The top of the filled area is covered to reduce rainfall infiltration and the water which does not enter the landfill is removed by the drainage pumps and a sump located at one of the lower corners of the sanitary landfill. The water is pumped out of the landfill for treatment or controlled discharge. If consideration is only given to collecting the leachate and not controlled discharge, the potential damage that the leachate represents may be considerable.[64] A pond of leachate with a high concentration of contaminants may buildup in the landfill. A rupturing of the liner would release a high volume of this leachate.

7.5.4 Surface Waters

The objectives of the Federal Water Pollution Control Act Amendments of 1972 are the restoration and maintenance of surface water quality. Accordingly, all point source discharges of pollutants such as collected leachate, surface runoff, and diverted groundwater must comply with state NPDES permit requirements. The permit requirements are site specific in that they depend upon the designated use of the surface water and the water flowrate. The criteria also require the prevention of contaminated discharge into surface waters of nonpoint sources when possible.

Leachate seepage and surface runoff should be collected through ditches or trenches. The amount of water which enters the landfill site or moves laterally as groundwater into the deposited refuse should be controlled. The possibility of water entering a landfill site must always be taken into account. Water contamination by infiltration is of concern when the solid waste is placed where there is relatively unhindered flow from the solid waste to the surface of groundwaters and when the distance from the landfill to the surface water is unusually short. The waste should not be placed where there is standing water, over coarse soils or fractioned bedrock, or near wells or surface bodies of water. Special precautions should be taken to minimize water pollution for such sites. Diversion of the surface water will reduce mud and standing water on the site as well as reduce leachate production. A conduit can be provided to channel streams through or under a landfill to eliminate contact with the solid waste. Runoff from the landfill should be diverted to one central point where it can be discharged to a water body or treated prior to discharge. One technique is to build a simple diversion barrier at the top of the sanitary landfill to keep runoff from entering the fill surface. The top cover material of the sanitary landfill should be graded to reduce the residence time of the surface water, since the quantity of water which infiltrates the landfill is a function not only of the permeability and the thickness of the cover but the length of time the water stands on the surface.

One of the basic concepts of sanitary landfill design is that groundwater and the deposited solids should not be allowed to interact. It should not be assumed that the leachate will always be diluted in the groundwater since the flow in the aquifer is usually laminar with little mixing.[50,64] When issuing landfill permits, many states require that groundwater and deposited solids be from two to thirty feet apart. Approximately five feet will remove enough readily decomposed organics and coliform bacteria to make the leachate bacterialogically safe.[66] Mineral pollutants from iron and steel wastes, however, can travel long distances through soil or rock formations. The proposed rules for site selection for hazardous wastes require at least 1.5 meters (5 feet) above the historical high water table.

It is often possible to lower the groundwater in freely draining, gravelly, and sandy soils. Drains, canals, and ditches are frequently used to intercept an aquifer and channel it to the surface or a recharge area at a lower elevation.[64] Temporary methods of lowering the groundwater such as wells are not advisable because the wastes can become saturated with water after the pumping ceases. Also, highly permeable soils that can be readily drained will offer little resistance to leachate movement.[64]

A major preventative measure for reducing the possibility of the pollution of surface waters are to locate the site a safe distance from streams, lakes, wells, and other water sources. The landfills should not be located above the kinds of subsurface stratification that will lead the leachate to water sources such as fractured limestone.[64]

7.5.6 Flood Plains

If a facility is located in a lowland or relatively flat area adjoining inland and coastal waters which are inundated by a flood which has a one percent or greater chance of reoccurring in any year, then the facility must meet three criteria: (1) it must not increase the flooding upstream by preventing the flow of water across the landfill site; (2) the landfill also must not reduce the water storage capacity of site, which increases the flooding downstream; and (3) the flood water must not inundate the waste material.

The acreage of the flood plain consumed by the land disposal site should be minimized. The nature of the waste should also be considered and the permissible wastes in a flood plain should be limited to the more inert types.

A landfill located in a flood plain should be protected by dikes and liners.[64] The top of the dike should be wide enough for maintenance work to be carried out and may be designed for use by collection and landfill vehicles.

The location of sanitary landfills in flood plains are discouraged since the wetlands, surface water, and groundwater may be more sensitive to effluents from the landfill. The EPA feels that although the environmental impact of an individual site may be minimal the cumulative effect could be significant.[53]

7.5.7 Safety

Surface ponding of certain coke plant wastes and other liquid wastes are not acceptable if the gases produced from the liquid either by sublimation or evaporation cause either a public nuisance or endangerment of the health. The use of hazardous organic liquids for dust control is also undesirable for these reasons. One major criteria for a sanitary landfill is the controlled access to the disposal site. Complete prohibition of access to unauthorized users is the most effective means of minimizing the risk of injury to other persons. In most cases there is little economic impact on solid waste disposal operation in accomplishing site access control.[53] Potential harm to the landfill personnel can be minimized with proper training and safety practices.

7.5.8 Other Criteria

Whenever possible environmentally sensitive areas should be avoided. Other areas that are sensitive include active fault zones and karst terrain, wetlands, and endangered species habitats. Sensitive areas may not be used unless it is demonstrated that the facility will not jeopardize the biological life in the area. Lined landfills should not be located over future mining sites, abandoned mining sites, or unstable surfaces due to the potential rupturing of the liner.

8.0 IRON AND STEEL RECOVERY AND RECYCLING

There are four basic categories of solid waste from iron and steelmaking: coke plant wastes, slags, iron oxides, and scrap. Essentially all scrap is recycled to the steelmaking furnaces. Coke plant wastes are also recycled to various operations with the exception of wash oil and tar sludges which are only partially recycled and lime sludge which is landfilled. Ironmaking slag and, to a minor extent, steelmaking slag as well, are sold for by-product use. The remaining steelmaking slag is either partially recycled to the blast furnace or landfilled. A substantial portion of the iron oxide wastes, especially steelmaking dusts and sludges are landfilled; the rest are recycled to the sinter plant.

At present, various waste recovery processes are being implemented to increase the utilization of iron oxide wastes. These include pelletizing of the wastes to make them suitable for charging into the blast furnace, direct reduction to remove and recover otherwise deleterious zinc and lead, and deoiling to facilitate the use of certain iron oxide sludges in the entire plant.

Various changes in the iron and steelmaking process, primarily implemented because of economics, are also reducing the consumption of raw materials and the generation of waste products. These changes include continuous casting for better yield of semi-finished product, preheating of scrap and molten iron to consume more scrap in steelmaking furnaces, and various modifications to improve ironmaking in the blast furnace. The latter include external desulfurization of iron, burden preparation, and fuel injection in the tuyeres. Direct reduction of iron ore is also growing because it requires less investment than the blast furnace/coke oven alternative.

The full implementation of the above process changes in the industry would increase the consumption of scrap (23 percent) and reduce the consumption of coal (35 percent) and fluxes (24 percent). It would also reduce waste generation in terms of coke plant wastes (35 percent), iron oxides (14 percent), ironmaking slag (34 percent), and home scrap (22 percent). The reduced generation of scrap, combined with its increased consumption would provide an incentive for scrap recovery.

8.1 WASTE TREATMENT AND RECYCLE

This section discusses the current practices used to recycle wastes including special treatment and handling procedures. Some of the most common methods of resource recovery and recycle are described, as well as identification of promising new uses for waste materials. One example of how the iron and steel industry can increase the resource recovery from other segments of the economy is discussed briefly.

8.1.1 Coke Plant Wastes

Coke plant wastes, particularly tars and oils, should be recycled or burned in an oxidizing atmosphere whenever possible. Although the composition and quantity of these wastes is determined by the recovery and operating practices used, the ones of interest are: coke breeze and residues, by-product coke gases and tar sludge, ammonia still lime sludge, and wash oil sludge.

A wide variety of processes exist to capture and treat by-product coke gases and various combinations of these processes are practiced throughout the industry. Due to the carcinogenic and toxic nature of coke oven by-products, special environmental considerations should be given to them.

Coke breeze is small particles (36 kg per tonne of coke) screened from the coke before it is charged to the blast furnace. These particles are too small to be charged into the top of the blast furnace because the furnace draft would only blow them out the top. Also, the breeze could interfere with the permeability of the burden. The breeze and residue from pollution control devices are recycled through the sinter plant as fuel, recharged into the coke oven, used as soaking pit lining, or, infrequently, briquetting. It is sold as product only when there is an excess.

Tar sludge collects in the tar decanter and various storage tanks. Particulates entrained in the tar and coal and coke fines collected during coal charging accumulate in the sludge also. The composition of the sludge is expected to be suitable for recycle into the coke ovens or agglomeration processing in a reducing atmosphere.

Ammonia still lime sludge is formed when tar and oils in the ammonia water encapsulate the particles in the lime slurry. In general, this sludge is disposed of by landfilling.

Wash oil sludge accumulates in the oil used to scrub light oils from the coke oven gas. Currently the sludge is either burned in an open hearth furnace or recycled through the coke ovens.

8.1.2 Iron and Steelmaking Slags

One-third of the industry-generated solid waste is slag. Slags are required in metallurgical processing to remove unwanted elements such as sulfur and phosphorus and also to protect the metal from reacting with the hot gases.[18] Apart from the metallurgical use, slags have a wide variety of non-metallurgical uses also. There are three major types of blast furnace slags: air-cooled, granulated, and expanded.

Air-Cooled Slag

Molten blast furnace slag is permitted either to run into a pit or transported in ladles and poured on the ground some distance away from the furnace. With either method, the slag is cooled and quenched with water to hasten the process.[67] After cooling the slag is dug, crushed, and screened to the desired aggregate and used for a variety of purposes. A magnetic pulley is often used to recover iron for charging into the blast furnace.

Some of the major useful properties of this slag are weathering and abrasion resistance and its noncorrosive nature.[67] Table 67 presents a summary of the uses of air-cooled slag. It is immediately obvious that nearly all the slag consumed in the United States is in the construction industry. The major uses include highway and airport construction as well as railroad ballast.

Whenever slag is economically available, it is used extensively as a coarse aggregate in many types of concrete.[67] Because of the voids in the slag, it is a preferred material for high strength and light weight. The slag aggregate pavements are reported to exhibit unusually high skid resistance. Slag has a unique combination of resistance to polishing and abrasive texture.

TABLE 67. USES OF AIR-COOLED BLAST FURNACE (1976)

Use	Quantity (thousand tonnes)	Percentage	Value ($/tonne)
Cement aggregate	1753	8.4	3.27
Bituminous construction	3691	17.7	3.08
Highway and airport construction aggregate	9713	46.6	2.90
Concrete block aggregate	270	1.3	3.39
Railroad ballast		16.5	2.23
Mineral wool	689	3.3	3.24
Roofing cover material	189	0.9	3.9
Roofing granules	12	0.06	4.48
Sewage trickling filter	10.9	0.05	6.05
Agricultural	55	0.26	3.66
Other uses	988	4.74	2.64
TOTAL	20,820		2.87

Other uses of slag include the production of a high quality mineral wool from it. The mineral wool is durable, lightweight, and has a high insulation value. Slag is extensively used as the granular material on composition shingles and roofing.[67]

Slags have been used to condition soil with respect to basicity and humus content. The lime in the slag is in a useful form since it is slowly leached out and does not burn like ordinary lime. Although slags which are used for agricultural purposes are not fertilizer, they do contain some fertilizing elements. Slags have been used as soil conditioners for almost a century.[18]

Whenever slags are used to condition soil, special consideration should be given to the long range effect of heavy metals such as cadmium. Special criteria have been proposed by EPA for the use of waste for the production of food chain crops.[53] At the present time, the criteria only address cadmium but other metals will be addressed in the future, as well as organics. The current criteria establish the amount of cadmium which can be added per acre, as well as restrict the use of solid waste which contains greater than 25 ppm of cadmium for the production of food chain crops. Additional slag composition information may be required to establish the environmental impact for its use in agriculture.

Granulated Slag

Granulated slag is formed when the molten blast furnace slag is rapidly chilled, thus preventing the formation of crystal structures. Depending upon the composition of the slag and the chilling process, the structure can vary from a friable, popcorn-like structure to grains resembling dense glass.[67]

Granulated slag has excellent hydraulic properties so that it will set up similar to cement when compacted in the presence of water.[67] When properly compacted, it can be used as a base for pavements, runways, and parking areas because it increases the support with age. Table 68 demonstrates the relative amounts of granulated slag used in a variety of applications.

TABLE 68. USES OF GRANULATED BLAST FURNACE SLAG (1976)

Use	Quantity (thousand tonnes)	Percentage	Value ($/tonne)
Road construction and fill	1090	74.1	2.14
Agriculture	53	3.6	3.13
Cement	79	5.4	4.22
Concrete block aggregate	113	7.7	3.99
Other uses	134	9.1	1.79
TOTAL	1471		2.34

Granulated slag is used in the manufacture of portland blast furnace slag cement. The slag constituent is between 25 and 65 percent by weight. The slag cement can be used in combination with portland cement in making concrete and with lime in making masonry mortar.

Expanded Slag

Expanded slag is obtained by the controlled expansion of molten blast furnace slag with water or air. A variety of techniques are employed for expanding the slag, the physical properties of it depending upon the technique used for the expansion. The cellular structure is more pronounced than with air-cooled slag. Expanded slag is commonly used as an aggregate for concrete block manufacturing. Other uses include lightweight, structural concrete and use as a lightweight fill. Slag has good compatibility in concrete mixes and possesses a number of desirable properties. For architectural purposes, the high sound transmission loss and the light surface texture are desirable.[67] The higher insulating values of this type of slag masonry units provide better protection against condensation on walls and reduce energy requirements for heating and cooling. Expanded slag is also very useful for creating embankments since it is easily compacted and has good drainage and an inherent cementing action. Some of the uses of this slag are presented in Table 69.

TABLE 69. USES OF EXPANDED BLAST FURNACE SLAG (1976)

Use	Quantity (thousand tonnes)	Percentage	Value ($/tonne)
Concrete block aggregate	1271	93.7	5.02
Lightweight concrete	8	0.6	5.74
Other uses	77	5.7	2.34
TOTAL	1356		4.87

Steel Slag

Steel slags are fundamentally different from blast furnace slag and consist of calcium silicates, calcium oxide-ferrous oxide solid solutions, oxides, and free lime. There is variation in composition due to the batch nature of the process. The calcium and magnesium oxides can be hydrated with expansions of up to 10 percent. This uncontrolled expansion severely limits the use of steel slags in portland cement concretes, since expansion can destroy the concrete. Structural failures can result from the indiscriminate use of steel slag in confined applications.[69] The hydration of unslaked lime occurs rapidly (several weeks) but magnesium oxide hydrates more slowly (several years).

Aging for a period of at least six months can be useful in controlling the expansion.[68] Several treatments can be used to accelerate the expansion of the slag, thus reducing the expansion in use. When the metallics are recovered by crushing, and water is used in processing, the aging process is accelerated.[69] Spent pickle liquor (H_2SO_4) has been used to accelerate the aging of slags, and the effectiveness of the treatment is related to the contact time with the acid. This process is also expected to free some of the heavy metals bound in the steel slag.

These slags are used mainly for unconfined base fill and highway shoulders (Table 70). Steel slag is used as railroad ballast, although in substantially less quantities than air-cooled blast furnace slag.

One use of steel slag which has not been fully developed is the formation of very stable mixtures with asphalt. Some useful properties of this blend are good flow, very high stabilities (two to three times greater than current aggregates), adequate compactability, excellent stripping resistance, and good wear and skid resistance.[69]

An increasing amount of steel slag is being recycled to the blast furnace since 1972.[39] This is done to recover their iron and manganese contents, since these metals are reduced and become part of the iron. The lime content of the steel slag acts as a flux.[18] There are conditions under which the steel slag cannot be returned to the burden of the blast furnace. These include additions during specialty steelmaking, no recycling equipment available, non-integrated operations, and unfavorable economics.[69] With increasing raw material costs and high disposal costs, it is likely that a higher percentage of steel slags will be recycled in the future.

Basic open hearth slag has been used, especially in the southern states, as a soil conditioner. The high phosphorous content of the open hearth slag resulted from the high phosphorous content of local ores. Other open hearth furnace slags are used in areas for conditioning already phosphorous-rich soils

TABLE 70. STEEL SLAG USES (1976)

Use	Quantity thousand tonnes)	Percentage	Value ($/tonne)
Railroad ballast	423	7.0	1.51
Highway base or shoulders	2160	36.1	1.63
Paved area base	1557	26.0	1.66
Miscellaneous base	1284	21.4	1.62
Bituminous mixes	321	5.3	1.59
Other uses	244	4.1	1.54
TOTAL	5989		1.62

because of the amounts of elements such as iron, boron, zinc, molybdenum, and copper which are needed in states such as Florida.[18]

8.1.3 Iron Oxide Recycling

Iron oxide wastes in the form of dust, scale, and sludge comprise over 20 percent of the steel industry's process wastes that are landfilled, and are probably the most valuable with respect to potential resource value. Sinter and blast furnace dusts are presently recycled to the sinter plant to recover iron and carbon values. About 70 percent of the mill scale can be readily recycled with the heavy, coarse pieces delivered directly to the blast furnace and smaller pieces incorporated into the sinter mix. A few plants may be unable to use scrap containing zinc and lead in steelmaking so that the dust can be recycled, or they may segregate the dusts for those periods of time when such scrap is used.

The balance of the mill scale, sludges, and steelmaking dusts are not routinely recycled due to the presence of oil, water, tramp elements (zinc, lead, and alkalis), and/or small particle sizes (fines). These wastes will be examined with respect to dealing with the problems of recycle, namely agglomeration to solve the fines or water content problems, tramp element removal, and de-oiling to eliminate the hydrocarbon emissions problem.

Agglomeration Processes

Many agglomeration processes are available and have proven successful in producing hard briquettes or pellets than can be handled, transferred, stored, and charged to the blast furnace or steelmaking furnace. The application of these processes would be limited to those specific locations where the tramp element content does not present a serious problem since no provision is made for zinc and lead removal.

The Reclaform process was developed by the Reclasource Corporation of Chicago, Illinois and has been successfully used in a demonstration plant. A hot mix of iron and carbon wastes is briquetted with a binder and cured by baking to form a strong coke bond. For example, coke breeze, furnace dust, oily mill scales, filter cakes, and sludges can be agglomerated with a carbonaceous binder (e.g., coal tar pitch) to yield a strong, durable briquette. A 20-day trial was conducted at Crucible Steel (Midland, PA) in which the briquettes were successfully utilized as 10.5 percent of the blast furnace burden.[70] Both iron and carbon values were recovered in the Reclaform test. The company is developing detailed engineering plans for a 318,000 tonne per year (350,000 tons per year) plant that is still in the planning stage. No commitments have been made for construction, but tentative plans are targeted for 1981 at a cost of approximately $10 million. A company spokesman stated that a 100,000 ton per year facility would be the minimum size that could be economically feasible, with an estimated capital requirement of $5 million.[71]

The Pelletech Corporation of Pittsburgh, PA has demonstrated an alternative for handling waste fines with a process called the MTU cold-bond process. This procedure takes ground mill scale, blast furnace dust, and steelmaking dust and combines 4-5 percent burnt lime and 1-2 percent silica flour. These solids are then mixed with water, aged for several hours to assure complete hydration of the lime, pelletized in the form of balls, and then dried. This process was successfully tested during a two week run at Kaiser's Fontana (CA) plant where the balls were used as 10 percent of the burden in the blast furnace. A Pelletech representative stated the minimum economical plant size is 150,000 TPY, but he added that research is continuing with hopes of developing an economical 25,000 TPY process. The company is currently offering to build, operate, and finance a pelletizing plant with a long term contract to cover certain fixed charges for any interested steel plant. The pellets will be made from iron oxide wastes and will be sold to the steel plant at a cost less than the value of the contained iron.[72]

Republic Steel has been operating a 10 ton per hour briquetting facility using the Aglomet process at its Chicago plant. Waste materials include blast furnace dust and sludge, EAF dust, Q-BOP filter cake, mill scale, scarfing dust, and slag fines. These wastes are hot-briquetted in a fluidized bed at 870-980°C, and are being stockpiled for a blast furnace test at a later date.[70]

The COBO process licensed by Sala International is similar to the MTU process and has been demonstrated in Sweden for pelletizing chromium ore fines. This process also uses grinding, blending with lime and silica, balling, and then hardening to form cement-type calcium silicate bonds. Although it has not been demonstrated in the steel industry, the COBO process should be feasible in agglomeration of iron oxide wastes.[70]

Granges Engineering of Sweden has developed a pelletizing procedure called the Grangcold process. Coke breeze, mill scale, and steelmaking dust are wet ground in a ball mill, mixed with portland cement, and then balled. The pellets are hardened in bins for six days, then cured two to three weeks out-of-doors to complete the hardening process. No commercial facility has yet been built to use this process in the handling of plant dusts.[73]

The Blocked Iron Corporation has developed a carbonate bond pelletizing process in which the wastes are mixed with coal and 10 percent lime hydrate. The mixture is balled, dried, and carbonated in a carbon dioxide rich atmosphere. A blast furnace trial has been conducted in which the pellets performed satisfactorily and no operating difficulties were encountered.[70]

The Obenchain system is another cold-bonding process that uses a modified lime-silica combination as the binder. In April 1971, a pilot plant was installed in Trenton, Michigan. During its operation, this plant produced 12,000 tonnes of pellets that were used in McLouth Steel's blast furnaces for up to 20 percent of the burden.[73] This operation was stopped due to a change in McLouth's operation that reduced the amount of iron ore fines.[74]

A technique for recycling some steelmaking dusts back into the steelmaking furnaces has been practiced by U.S. Steel. When used in these furnaces, the agglomerated product does not have to be as strong as required in the blast furnace and some tramp elements can be tolerated. The dry dust is mixed with water in a balling disc to produce pellets that can be transferred and exposed to high temperatures without disintegration. This has been practiced for three years at U.S. Steel's National-Duquesne plant where almost all of the EAF dust has been balled and recycled back to the EAF. No operating problems have been observed and a benefit of reduced fluorspar usage has been noted.

Recycling pellets to the steelmaking furnace has two effects. One is to supply a portion of the iron oxide which is dissolved in the slag, increasing the metallic yield. A negative aspect is that more energy is required to reduce the iron oxide than it does to melt the scrap, or refine the molten iron, that it replaces.

Pellets were produced from open hearth dust at U.S. Steel's Homestead Works as a partial substitute for the ore charge in the open hearth furnace. A two-day test revealed no operating problems or changes in yields or heat times. The sulfur content of the melt increased 0.003 percent. An extensive test of this procedure was conducted at U.S. Steel's Youngstown Plant over a three-month period without operating problems. The sulfur content of the melt increased 0.004 percent and required additional lime, but the data suggested that the open hearth dust could be recycled for an extended period of time in the open hearth furnace.[70]

Bethlehem is using similar procedures at its Sparrows Point, MD and Bethlehem, PA Plants based on their U.S. Patent No. 4,003,736 and No. 4, 004,916. At Sparrows Point, sludge is collected from wet scrubbers on the open hearth and BOF furnaces and goes to a thickener. The slurry is then spray dried, fed to an impactor, and agglomerated in a pelletizing disc. The agglomerate is recycled back to the BOF or open hearth furnaces. At the Bethlehem plant, the steelmaking fume is collected as a dust, mixed with water in a pelletizing disc, and converted into balls. These balls are then recycled through the sintering plant. The Bethlehem unit turns out 110 tonnes per day and the Sparrows Point unit produces 273 tonnes per day. The cost of installing these pelletizing units can be recovered in savings by reducing the outside purchase of iron ore and pellets.[75]

Direct Reduction Processes

Because of their fine size and the presence of zinc, lead, and alkalis, steelmaking dusts and sludges have been considered unsuitable for recycle through the sinter plant and blast furnace. Zinc is particularly troublesome since it can affect blast furnace productivity by (1) reducing furnace permeability and forming scaffolds, (2) degrading refractory lining, and (3) forming blockages in the gas cleaning system.[76] The direct reduction processes convert steelmaking dusts with a high zinc content to pellets with a high level of metallized iron and low zinc, lead, and alkali content. The tramp elements are volatilized and concentrated in the offgas dust which may be sold to zinc smelters if the zinc content is high enough. Several of these processes have been tried and proven technically feasible, but the economic feasibility is still debated in the U.S.

Full scale application has found wide acceptance in Japan and seven commercial direct reduction plants are in operation and use processes that are very similar. A generalized flowsheet is shown in Figure 24 that is applicable to the Kawasaki, SL/RN (Stelco-Lurgi/Republic National) and Sumitomo dust reduction processes. The waste solids are mixed together, pelletized, preheated on a grate, and then reduced at 1100-1150°C in a rotary kiln. Carbon in the dust, added coke breeze or coal serve as reductants. Approximately 95 percent of the lead and zinc are removed as well as 50 percent of the Na_2O and K_2O (alkalies). The metallized pellets are cooled and sent to the blast furnace, and the zinc oxide dust collected from the offgas can be used by zinc processors.

The Kawasaki Steel Corporation recently (1977) installed its third direct reduction plant at a cost of $24 million. With a 600 tonne per day capacity, this required an investment of $110 per annual tonne of output pellets.[77]

A representative of Kawasaki Steel said that their direct reduction plants were still in operation and were economical. He also stated that a U.S. engineering firm is negotiating to license their technology.[78]

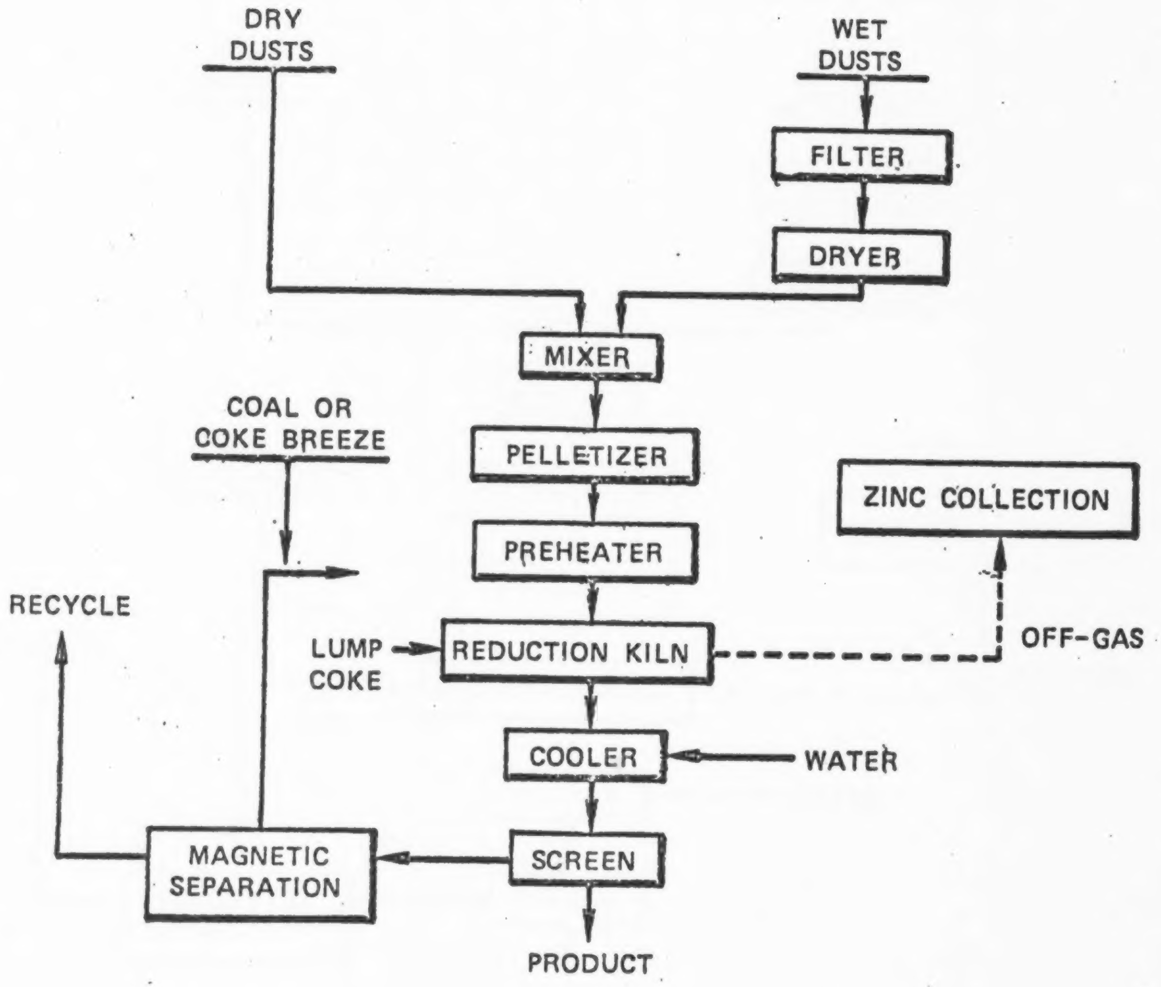


Figure 24. Waste-dust grate-kiln direct reduction process flowsheet.[70]

(M.M. Harris. "The Use of Steel Mill Waste Solids in Iron and Steelmaking." Copyrighted by American Iron and Steel Institute, 1978. Reprinted by permission.)

Sumitomo has two plants operating, one that produces reduced pellets for the blast furnace and one producing dezinced material for the sinter plant. The latter type of plant requires lower capital investment since an existing sinter plant is used for agglomeration in lieu of building a pelletizing plant. However, oxidation of the metallic iron makes the sintering route undesirable. A Sumitomo representative felt that the use of the zinc dust for zinc recovery and strict landfilling regulations made the process economical.[79]

Nippon Kokan K. K. (NKK) has utilized the SL/RN process in a 360,000 TPY plant since 1974. Their representative said the plant was still operating and was economical in 1974, but that the rising cost of energy in recent years may make the economics marginal.[80]

The seven Japanese direct reduction recycling plants have an average capacity of 233,000 tonnes per year, and are located at large steelmaking complexes.[70] A regional treatment facility may be required in the U.S. if American steel companies are to take advantage of the economy of scale (Section 6.2.5). Few individual plants in the U.S. generate 100,000 to 400,000 TPY of dust with a high zinc content and recovery of the zinc may be a controlling factor in an optimistic economic evaluation.

A U.S. source estimates an investment cost of $138 per annual tonne of reduced pellets for a direct reduction plant, and states the energy requirements can range up to 4 million kilocalories per tonne of pellets.[81] Some of this energy will be recovered in blast furnace fuel savings due to the metallized iron content of the pellets. Savings on land disposal costs and credit for the zinc dust would also help to recoup operating expenses. However, although several of these processes have been tried and proven technically feasible, the economic feasibility is still being debated in this country.

The Waelz process is a direct reduction technique that has been used for 20 years to refine low grade zinc ores. The Berzelium and Lurgi companies have conducted a large scale experiment in Duisburg, Germany, that used iron and steelmaking dusts. Mixtures of waste dust containing 40 percent blast furnace sludge and 60 percent BOF dust that was analyzed at 44-50 percent iron, 2.5-4.5 percent zinc, 1-2 percent lead, and 3-8 percent carbon were reduced in the Waelz kiln. The feed was prepared by simple mixing, and after reduction, the fines were briquetted with sulfite waste liquor as the binder. These briquettes were used at a rate of 160 kg/tonne iron in the blast furnace for 16 days and no variations in the metallurgy were noted.

The experimenters observed that dezincification was possible with a continuous process, 95 percent of the zinc and 50 percent of the alkalis were removed, and 95 percent of the iron was metallized. The advantages of this process are that it can operate economically on a lower throughput (100,000 TPY) than other direct reduction processes and it is less sophisticated in that there is no pelletizing before reduction. The sponge iron product may be charged to the steelmaking furnace, or it could be briquetted after reduction. A valuable zinc by-product (Waelz oxide) is recovered from the offgas, and oily mill scale can be used in the kiln feed with no adverse effects.

Lurgi provided a cost estimate for the production of reduced pellets at a May 1978 symposium (Table 71).[82] The processing cost of $240 per tonne does not appear economical when considering that the Midrex Corporation sells reduced iron pellets to steel companies at $120 per tonne.[83] However, other factors that may improve the economics and must be considered for specific cases include (1) the availability of reductant (carbon) from coke plant wastes at a much lower cost, (2) the value of the zinc oxide by-product, and (3) savings on landfill charges.

Inland Steel participated in a pilot plant test of the classical Waelz process in cooperation with Heckett Engineering and the Colorado School of Mines Research Foundation. The conclusion was that the process was not satisfactory for commercial application due to the low compressive strength of the pellets, loss of iron oxide into the zinc precipitate, and high rate of recirculation of fines. Another program was initiated with Heckett Engineering, Stirling Sintering, and the Krupp Company to investigate the Krupp process, a modified version of the Waelz process. The program was technically successful but commercial application was dependent on the regional plant concept. The economics dictated a minimum 364,000 tonnes per year facility to service the Chicago area steel mills.[84]

TABLE 71. COST ESTIMATE FOR WAELZ PROCESS (400,000 TPY PLANT)[82]

Expense	Quantity (per tonne of feed)	Cost* ($ per tonne of feed)
Reductant	270 kg carbon	102.40
Heating agent	---	18.45
Electric energy	40 kwh	5.17
Water	1 m^3	1.85
Binder	18 kg	9.96
Utilities	---	0.92
Brickwork	1.2 kg	2.58
Repair, maintenance	---	16.42
Personnel	0.35 hr	12.92
Amortization and interest		69.19
Processing cost + amortization + interest		239.86

*Assumptions:

1. 15 percent annual interest.
2. Capital costs include 15 percent for infrastructure.
3. Includes a briquetting charge of $27.68/tonne.
4. Exchange rate of 0.542 marks = $1.00 (1/16/79).

Obenchain has also developed a direct reduction process that was demonstrated at an American steel plant. ESP dust, open hearth dust, and coke fines were used to produce pellets that were charged to a cupola, melted, and yielded molten iron. No commercial application is in use in the U.S., but the company is planning a 40,000 tonne per year plant in Central America for iron ore reduction at a cost of $2.1 million.[74]

De-oiling

Scale and sludge generated in the rolling operations are contaminated with oil and grease that make recycling difficult. Because these materials contain oil, they may cause excessive stack opacities if recycled to the sinter plant. To avoid these problems, the plant often decides to dispose of the waste rather than recover it. The various options for dealing with the situation are:

1. Dispose of oily scale and sludge to landfill or stock for future use. This causes the loss of a valuable natural resource and presents the possibility of ground water contamination.
2. Recycle through the sinter plant by upgrading the air pollution controls for the windbox to cope with the opacity problem. If the control is by baghouse, this is not technically feasible because the oil vapors present would lead to bag blinding. If the control is by ESP, the control equipment is unable to control the oily vapors. If the control is by scrubber, the capture of oily vapors would require an inordinate consumption of fan power and of capital to install new control equipment.

   For example, consider an average sized sinter plant which produces 6350 MT/day of sinter. Gas flow would be about 490,000 MM^3/hr. The existing fan may require 2500 KW to provide 1150 mm of suction for process suction, including scrubber differential pressure. In order to effect control of oily vapors, another 750 mm of differential would be needed, thereby consuming 1500 KW more. The plant generally decides that economics favor the elimination of oily materials from the sinter mix over upgrading the windbox controls.
3. De-oil the scale and sludge. There has been considerable effort along these lines but generally without success to date. A possible exception is a process developed by Colerapa Industries, Inc. (Ravenna, OH) that has been used by the Steel Company of Canada. This process takes mill scale and sludge that have been dredged from lagoons and sends it through an oil scrubber, screening operation, and thickener. The de-oiled iron oxide is recycled to the sinter plant at a rate of 36,000 tonnes per year. The application of this process appears to be based on pollution control requirements.[85] The detailed economics of this process is unavailable.

The development of successful methods for de-oiling would be an advantage to resource recovery and to the elimination of solid waste.

8.1.4 Waste Pickle Liquor

Steel finishing requires pickling, or acid dipping, to remove the black oxide scale that forms during the process. This is required not only for aesthetic reasons but is a mandatory step prior to cold rolling. The disposal of the tremendous quantity of acid consumed in this process is a major environmental problem and recovery of the chemical value in waste pickle liquor has been an objective in past decades. However, until 1976 there were no economical recovery processes available for HCl pickle liquor.[88]

The economic changes during the 1970's have generated an increasing interest in reassessing the possibilities of pickle liquor recovery. From 1972 to 1977 the cost of acid and its disposal have increased 150 percent. Regeneration costs during this period increased only 50 percent, and since 1976, the trend continues to indicate that resource recovery is the more economical method.

The pickling of steel was formerly done with sulfuric acid, which is still relatively inexpensive. In recent years, however, the industry has discovered that hydrochloric acid gives better results in half the time, thereby enabling an increase in production rates without additional capital expense. Much of the industry is now depending on hydrochloric acid to achieve their normal production rates. The elimination of fluorocarbon aerosols, the manufacture of which produced hydrochloric acid as a by-product, and changes in the oil industry's operating methods, have reduced this supply, and resulted in prices three times that of sulfuric and supplies of questionable dependability. These factors together with environmental requirements to abstain from spent acid dumping are creating a new interest in acid recycling.

Acid Regeneration

The Ohio River Valley Sanitation Commission initiated a pilot plant program in 1952 to make use of the Blow-Know and Ruthner double cycle acid regeneration process.[86] It was reported in 1958 at the general meeting of AISI to be a technical success.[135] It is the only known process that actually regenerates sulfuric acid from the iron sulfate produced by pickling.

The iron sulfate is converted to iron chloride in a regeneration plant by reaction with hydrochloric acid, producing sulfuric acid as a by-product which is recycled to the pickling plant. The iron chloride is roasted to recover the iron oxide for recycle. The complexity of the process was considered unsuitable for steel plants.

Acid Recovery

The only successful and continuing process for recovering sulfuric pickle liquor is an acid recovery process. This process essentially purifies the waste pickle liquor (WPL) by removing the $FeSO_4$ so that the unconsumed acid remaining is available for use. This reduces acid consumption by 50 percent in most plants.

Unlike the case with hydrochloric acid, the buildup of iron sulfate in H_2SO_4 solution significantly decreases the activity and reaction speed, and results in the pickle liquor being discarded when it is still 8 percent H_2SO_4.

In the recrystallization process, WPL is cooled to a low temperature, sometimes after evaporative concentration. Crystals of iron II sulfate hepta hydrate form as fast as the solution is cooled. These are removed by decantation or centrifugation.[87] The remaining purified liquor is strengthened by the addition of acid and returned to the pickle tanks. The ferrous sulfate formed can be sold for use in inks, dyes, paints, fertilizers, and as a flocculating agent in waste treatment and sewage plants, an expanding market. In 1976 there were only 20 recrystallization plants in North America, three were continuous process systems (2 in Canada) and 17 were batch processes.[19] Sulfuric acid has always been consumed in proportion to a Nation's productivity and is still relatively inexpensive at $27/tonne. Thus, the major incentive for sulfuric acid recovery is as a solution to the waste disposal problem.

Hydrochloric Acid Regeneration

The pickling of steel with hydrochloric acid produces ferrous chloride, which is dissolved in the pickling acid. The activity of acid chloride solutions is very high resulting in a usable pickling speed until all but one percent of the acid is consumed. The only practical operation that can be performed on the hydrochloric WPL is to regenerate HCl from $FeCl_2$. There are several processes that differ in approaches but all involve reacting iron chloride with water in the presence of heat to produce iron oxide and hydrochloric acid.

Spray Roaster Type Process

In the Pennsylvania Engineering/Woodall Duckham spray roaster process, the spent liquor is sprayed into the top of a cyclone-like chamber. Fuel and air are blown into the bottom of the chamber tangentially. The liquor undergoes the chemical reaction at around 1000°C and produces a powder of Fe_2O_3 that falls to the bottom. HCl gas and water vapor are also produced and are passed on to a scrubber and absorber to recover an aqueous solution of HCl. The Ruthner Industrieanlagen of Austria also makes these plants. The major advantage of this system is that the fine powder form of Fe_2O_3 commands a high price from the ceramic magnet industry ($176/tonne, 1978). The disadvantage of the process is that operational constraints require a roasting chamber at least 1.83 meters in diameter, making 4 liters per minute the minimum size reactor that operates satisfactorily. In all the thermal regeneration methods for HCl, 752 kilocalories per liter of waste pickle liquor is required. This amounts to 1/10 liter of oil per liter of pickle liquor.

Fluidized Bed Roaster

In 1936, Lurgi developed a roasting process in which the reactor is a fluidized bed of iron oxide. The waste liquor is sprayed into this and the Fe_3O_4 is recovered in the form of pellets. This is convenient for handling but does not command as high a price as the powdered Fe_2O_3. This process is efficient, recovering 99.5 percent of the acid, with almost complete absence of iron in the regenerated acid. Such purity, however, does not improve the pickling process.

Sliding Bed Regeneration

The sliding bed reactor was designed to be suitable for small installations of 20 to 60 liters per minute. Preheated waste pickle liquor (HCl) is sprayed on a bed of hot iron oxide that slides down an inclined furnace. Thermal decomposition converts iron chlorides into hydrochloric acid and iron oxide in the combustion zone of the furnace. The acid is vaporized and absorbed in water. At the bottom of the incline a system of buckets collects the oxide and carries it back to the top of the bed. Excess iron oxide is removed as required.[136]

Operational Aspects of Regeneration

Although articles have been written claiming that regeneration of HCl is economical, since 1976 the reputation that regeneration is not profitable in itself is still in wide circulation. Discussions with an industry source using spray roasting revealed that, of itself, regeneration is not profitable. The plants also have a high maintenance factor due to the abrasive nature of Fe_2O_3 and corrosion problems which are being solved incrementally. One manufacturer of pickle lines commented that when their customers learned that regenerating acid cost more than buying acid, they refused consideration of the topic.

The economics of acid regeneration are strongly influenced by the market available for the by-product iron oxide. The market for iron oxide in the production of magnets is estimated as 700 tonnes per year, much less than the industry could produce if all the pickle liquor was regenerated.

An industry source that does use regeneration revealed that continuation of the process was based on a wider view than just the cost of acid versus regeneration. The reasons given in favor of the process were:

1. Regeneration gives the company a guaranteed acid supply.
2. Regeneration eliminates disposal problems. It is cheaper than having the spent liquor hauled away in their location.
3. As an item of pollution control equipment, regeneration has a better payback than any other pollution control system.

This last comment indicates the importance of having acid regeneration systems classed as pollution control equipment for tax purposes.

Discussion with one U.S. steel producer presently enjoying cheap disposal in a deep well indicated that they are aggressively evaluating possible methods of regeneration because:

1. The cost and supply of HCl is uncertain for the future.
2. Their deep well could freeze up and be inoperable.
3. It appears that drilling another well may not be allowed.

Ten percent of hydrochloric acid used for pickling in the U.S. is regenerated, and 10 percent of sulfuric acid is recovered. Estimated comparison data with other countries are as follows: Japan-75 percent, France-40 percent, Germany-45 percent, Austria-50 percent, USSR-20 percent, United Kingdom-60 percent, Canada-75 percent, and Brazil-45 percent.

In summary, recycling waste acid has had a difficult development period in the U.S. probably because of a previous abundance of low cost materials and environmental standards. The future of recycling waste pickle liquor in this country looks promising due to changing conditions in the industry.

8.1.5 Scrap Recovery

Approximately 30 percent of the waste generation of iron and steel production is scrap metal. This metal is completely recycled and used to produce steel. EAFs can use a large amount of scrap metal as feed since energy is required to convert iron oxide to iron and the scrap is already in metallic form.

Obsolete scrap is also used in the steel industry. This scrap comprises worn out or broken products of the consuming industry and includes stoves, useless farm equipment, wrecked automobiles, etc. This scrap requires careful sorting to prevent contamination of the steel in the furnace with unwanted chemical elements that may be present in the scrap.

Due to the intrinsic energy value of scrap iron, as well as the material resource, the use of ferrous scrap from municipal refuse will be briefly considered. Scrap shortages are predicted by some experts in the iron and steel industry.[89] The amount of ferrous municipal scrap is estimated as 10 million tons annually, 10 percent currently used in ferroalloy and copper production.

When incinerated, municipal refuse contains 30 percent ferrous scrap in the residue. Incineration increases the copper content of the scrap, since the copper plates out on the metal. Incineration can also oxidize some of the iron as well as alloy the tin so that it cannot be removed.

Nonincinerated scrap can be altered to recover the iron for use in steel production. Magnetic separation is used to reject nonferrous material, and the composition of tramp elements is generally lower than for magnetically separated incinerated scrap. The aluminum content is somewhat higher in nonincinerated scrap, however. The tin can be removed from the nonincinerated scrap, or if the tin content is low enough, simple dilution with virgin material can lower the tin content in the hot metal to within acceptable bounds.

Useful scrap metal for the iron and steel industry can be obtained if the recovery system is properly planned and operated. This is a major area where governmental assistance can prove useful in resource recovery. Adjustment of transportation costs could also provide an incentive for scrap recovery.

8.2 EFFECT OF PROCESS CHANGES ON WASTE PRODUCTION

For the most part, steelmaking technology today is essentially the same as it was in the past century. There is still major reliance on the coke oven-blast furnace route of ironmaking as the first step in the steelmaking process. These processes have become larger and their control has become more sophisticated; however, their basic function has not altered.

Process changes that have come into wide utilization are sintering for agglomeration of fine ores and process wastes, the use of pelletized ore, the BOF to replace the open hearth, and continuous casting to replace conventional ingots. Even the BOF is but an update of the pneumatic process originally invented by Bessemer.

The steel industry is starting to direct its efforts toward some more basic changes in steelmaking. In general, these new methods will provide more continuous processing and greater containment of the processes than before. It is unlikely that these basic changes will come into any substantial utilization before the next century, due principally to the problems of raising the necessary capital, the conservatism of the steel industry towards the application of new technology, and in some cases, the additional energy cost.

In general, any innovation or improvement in steelmaking that increases its efficiency and reduces its costs also tends to reduce environmental problems, including generation of solid waste. At worst, the effect of the change on the environment is neutral. The net effect almost never results in deterioration of the environment.

Changes in iron and steelmaking practices fall into three categories in respect to their state of implementation in the industry. These categories are more fully described in the next paragraphs.

8.2.1 Changes Not Reduced to Practice

There are a number of radical changes in steelmaking technology which may have a substantial impact on the generation of solid waste. They have not been reduced to practice within the industry and their future is somewhat uncertain at this time. For this reason, only a brief description is provided for each.

Form-coking is a process alternative to conventional by-product coking. Its advantage is that it reduces the reliance on metallurgical grade coals and, because it is essentially continuous, it is comparatively easy to operate in an environmentally acceptable manner. Not only would form-coking reduce emissions to air and water, but also the production of solid waste as well. There are at least 10 distinct form-coke processes being investigated in the United States and the rest of the world. Projections are that two or three formed-coke processes will be available for adoption by the early 1980s.[90] Widespread implementation probably will not take place until the close of the century.

Nuclear ironmaking and plasma arc steelmaking are two technologies in which the thermal energy for the iron ore reduction process is applied in an unconventional manner. In either of these processes, coal or coke would be used solely as a reducing agent. In Japan, an eight-year research program has recently started on nuclear steelmaking. In the United States, some work has been done on plasma arc steelmaking, the biggest problem at present being the large amount of power consumed in the operation (estimated to be about 2000 kwh/t).

Direct steelmaking involves the injection of a mixture of coal and iron into a molten steel bath. Two versions of the injection process are contemplated. In one, electrical energy for the process is supplied by an inductor. In the second, heat is supplied by combustion of coal with oxygen in the injection jet. Figure 25 shows the two versions. It is stated that a 30-ton vessel will yield up to 12 tons of raw iron per hour.[91] This method of ironmaking, being based on powdered coal, eliminates the need for the coke ovens. It is also a method of producing sulfur-free fuel gas.

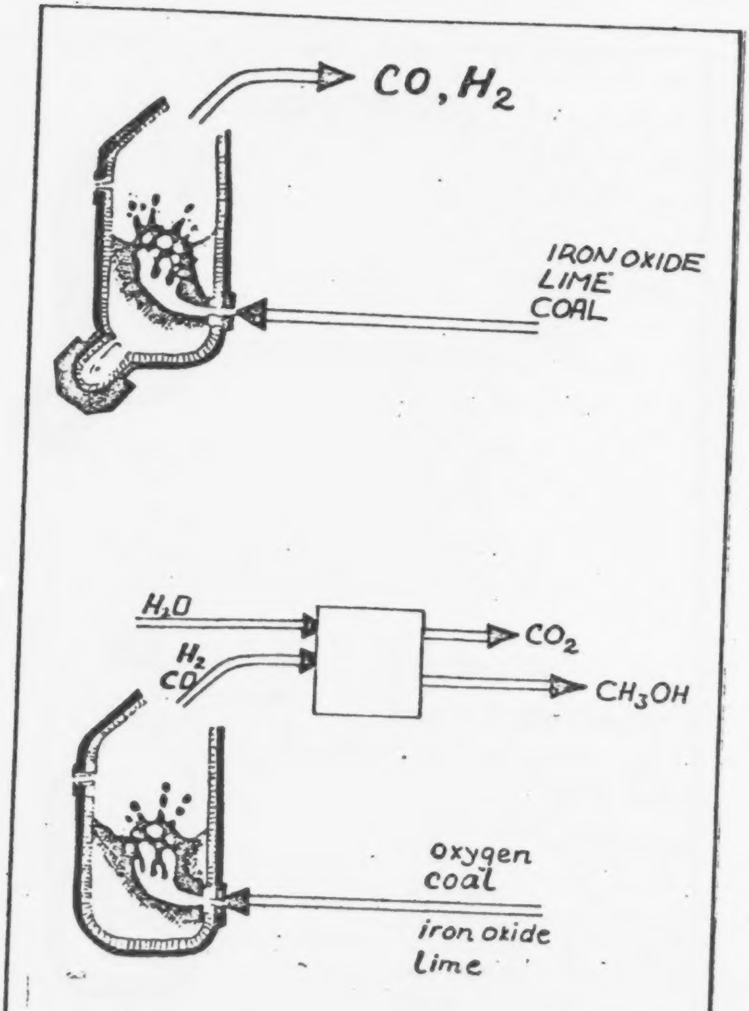


Figure 25. Two versions of the injection process for direct steelmaking.

(Iron and Steel Maker, October 1977)

Powder metallurgy provides a means of producing finished steel sheet from the compaction of iron powder. In this process, powdered steel is produced under controlled conditions, compacted into the form of a sheet, heat treated and then finished rolled to the final product. The process promises low capital cost, low energy cost, and a drastic reduction in rolling mill wastes, including solid wastes. Present-day deterrents toward the advancement of the process are product contaminants and customer resistance.

Because the implementation of the above-mentioned processes appears to lie well in the future, there will be little immediate impact from them on the generation of solid wastes. There will, therefore, be no further discussion or consideration of them in this report.

8.2.2 Processes Not Widely Used

There are three new practices that fall within this category. They are described briefly in the subsequent paragraphs and will be covered in more detail later on in this report.

Scrap preheating in the BOF provides thermal energy which permits scrap to replace a portion of the molten iron. In the EAF, scrap preheating can reduce heat time and consumption of electrical energy.

Superheating of molten iron before its admission to the BOF provides additional thermal energy to the process and allows scrap to replace a portion of the molten iron. This process is not used by the steel industry since there are no installations in operation at the present time. However, the equipment, a large induction furnace, is widely used in the foundry industry.

In cases where oil injection is used, dehumidification of the blast for the blast furnace provides smoother operation and reduction in coke consumption. Although not in use in the United States, it is currently being practiced in Japan.

8.2.3 Processes in Substantial Current Use

There are five new processes that have made substantial inroads into the steel industry. Each of these processes has an impact on the generation of solid wastes. Their further and immediate implementation is anticipated.

Burden preparation for the blast furnace consists of several stages of sizing and screening for the raw materials prior to their introduction into the process. All new blast furnaces are equipped for burden preparation and many existing furnaces have been retrofitted. The effect on the process is to provide smoother operation, reduced coke rate and reduced generation of solid waste.

Fuel injection into the tuyeres of the blast furnace provides a means of replacing an equivalent portion of the coke. A wide variety of fuels for injection have been used including gases, oil, and powdered coal. The reduction in coke usage is reflected in a reduction in emissions and wastes from the coke ovens. Most of the blast furnaces in the United States are equipped for fuel injection.

External desulfurization of iron is coming into wide use because it improves the productivity, coke rate, and flux consumption in the blast furnace. From a solid waste standpoint, in addition to reducing emissions from coke ovens, it also provides a substantial reduction in the generation of blast furnace slag.

Direct reduction of iron provides an alternative to the coke oven-blast furnace route of ironmaking. At the present time, its use is more prevalent outside of the United States than in it, there being only three relatively small domestic installations. Direct reduction is a relatively clean process which produces essentially only iron oxide dusts, thereby avoiding the organic wastes of the coke plant and emissions and slag of the blast furnace.

Continuous casting to produce semi-finished steel increases product yield, thereby reducing the generation of scrap and iron oxide wastes in the primary mill. A secondary effect of improved yield is a reduction in the consumption of molten iron and coke as well as their accompanying waste products. Approximately one-third of semi-finished steel in the United States is produced by this method.

8.2.4 Description of Process Changes

This section will discuss each of the process changes which were listed in Sections 8.2.2 and 8.2.3 above. The description will cover the nature of the process as well as its effect on other processes in the iron and steelmaking chain. It will also discuss its effect on the generation of solid waste as well as the comsumption of resources. Finally, there will be an indication of the status of applications in the industry, both present and future.

Blast Furnace Burden Preparation

The ideal burden for the blast furnace consists of lumps which are relatively uniform in size and free of fine particulate matter. The uniformity creates a highly permeable bed that permits the free flow of reducing gases. The absence of fine material not only contributes to improved permeability but also reduces the carryover of particulates in the top gases and the corresponding generation of dusts and sludges.

Creation of a suitable burden involves the crushing of lumps and the screening of fines. The latter operation, in particular, is ideally carried out as close to the entry of the furnace as is practical. In this manner, any fines which are generated in previous handling operations are kept out of the ironmaking process. All new blast furnaces will practice this technology to one extent or another.

Another aspect of burden preparation is to produce self-fluxing sinter. In this technique, the lime requirements of the blast furnace are furnished, substantially in their entirety, by limestone which has been incorporated into the sinter and calcined in the sintering process. It thereby replaces the introducton of limestone into the blast furnace, and by virtue of reducing calcining requirements in that unit, reduces coke rate.

In Japan, from 1955 to 1960, the intensive application of burden preparation in the blast furnace reduced the coke rate from 725 kg/MT to 625 kg/MT.[92] In the United States, probably one-half of the blast furnaces have essentially complete burden preparation. It is not unreasonable to expect that nearly all blast furnaces will adopt this technology within the next decade.

Extensive burden preparation has a direct effect on blast furnace operations in terms of increased production, reduced generation of solid waste oxides and coke consumption. Its indirect effect lies in the coke ovens which, having to produce less coke, yield a corresponding reduction in emissions to air and water and in the generation of solid waste from that process.

Fuel Injection in the Blast Furnace

The injection of auxiliary fuel through the tuyeres into the blast furnace is a relatively new technology which initiated in 1961. To accomplish fuel injection, an auxiliary circle pipe for the fuel is provided at the vicinity of the tuyeres. Injector pipes are placed within the tuyeres, terminating near the hearth of the furnace. The fuel that is injected through the tuyeres replaces a part of the coke burden.

A wide variety of fuels have been injected into blast furnaces. The replacement ratio expressed as kilograms of fuel per kilogram of coke saved varies with the fuel injected. As a general rule, the replacement ratio for oil or tar is 1.2:1, coke oven gas 1:1, and coal 1:0.9. In 1975, American mills saved 4 million tonnes of coke while melting 8 million tonnes of iron.[93] This equates to 50 kg/MTHM, or approximately 7 percent of the U.S. 55 million tonnes per year of coking capacity. At the present time, approximately 80 to 85 percent of the blast furnaces in the United States have been retrofitted to handle tuyere injectants.[94]

The newest blast furnaces being built for Bethlehem at Sparrows Point and for Inland Steel are designed to handle 100 kg/MTHM of injectants and are expected to operate with coke rates of 500 kg/MTHM. It will be noted that these coke rates are almost equal to the best practice in Japan and also that the injection rate is approximately twice the present average in the United States.[95] Within the next decade, it may be expected that nearly all of the blast furnaces in the U.S. will be equipped for fuel injection and that the average rate of injection will tend to double.

Injection of fuel through the tuyeres results in an endothermic reaction at the hearth level. Therefore, it is necessary to increase the temperature of the hot blast concurrent with the injection process. At the same time it is necessary to provide storage for the fuel, piping facilities, control facilities, etc. When coal is used as an injectant, facilities for pulverizing it and for avoiding explosions are also required.

Economics provide the incentive for installation of fuel injection at the blast furnace. The principal factor is that the auxiliary fuel is usually considerably cheaper than the coke it replaces. Another factor is that iron-making capacity may be increased without the necessity of providing additional coke ovens. The environmental advantage for this process is that it reduces the amount of coke that is produced and, along with this, a corresponding reduction in emissions to air and water and solid waste generation. From the standpoint of fuel conservation, if coal is used as the injectant in the blast furnace, since it replaces 0.9 pounds of coke, it also replaces 1.4 pounds of coal at the coke ovens.

Dehumidification of the Blast

This consists of a dry-type dehumidifier installed at the blast furnace blower. Dehumidification provides higher combustion within the blast furnace, lowers coke rate and increases pig iron output. The reduction in coke rate is approximately 0.75 kg/MT of pig iron for every gram per standard cubic meter of mositure removed. Since the mositure in the air varies with atmospheric conditions, the reduction rate will vary as well. Under average atmospheric conditions, the improvement is approximately 10 to 12 kg/MTHM. As indicated in the preceding sections, reduction of coke rate in the blast furnace provides environmental benefits by reduction in output from the coke oven.

External Desulfurization of Iron

The presence of excessive amounts of sulfur in steel produces such detrimental effects as cracking during processing and reduced physical properties. In order to keep sulfur within reasonable limits, generally accepted as below 0.020 percent in molten iron, it has been necessary to operate the blast furnace with a large quantity of basic slag. In recent years, there has been a deterioration in the quality of ore and coke which further increases slag volume.

It is well known that a leaner, less basic slag increases productivity of the blast furnace and increases solubility of bosh alkalies. The lean flux rate results in a more permeable, smoother operating furnace and a lower coke rate. The slag volume is reduced, but in contrast the sulfur content of the iron increases. In order to achieve the advantages in the blast furnace of the leaner slag and to cope with the sulfur in the metal, a recent development, essentially starting in 1972, is the external desulfurization of iron.

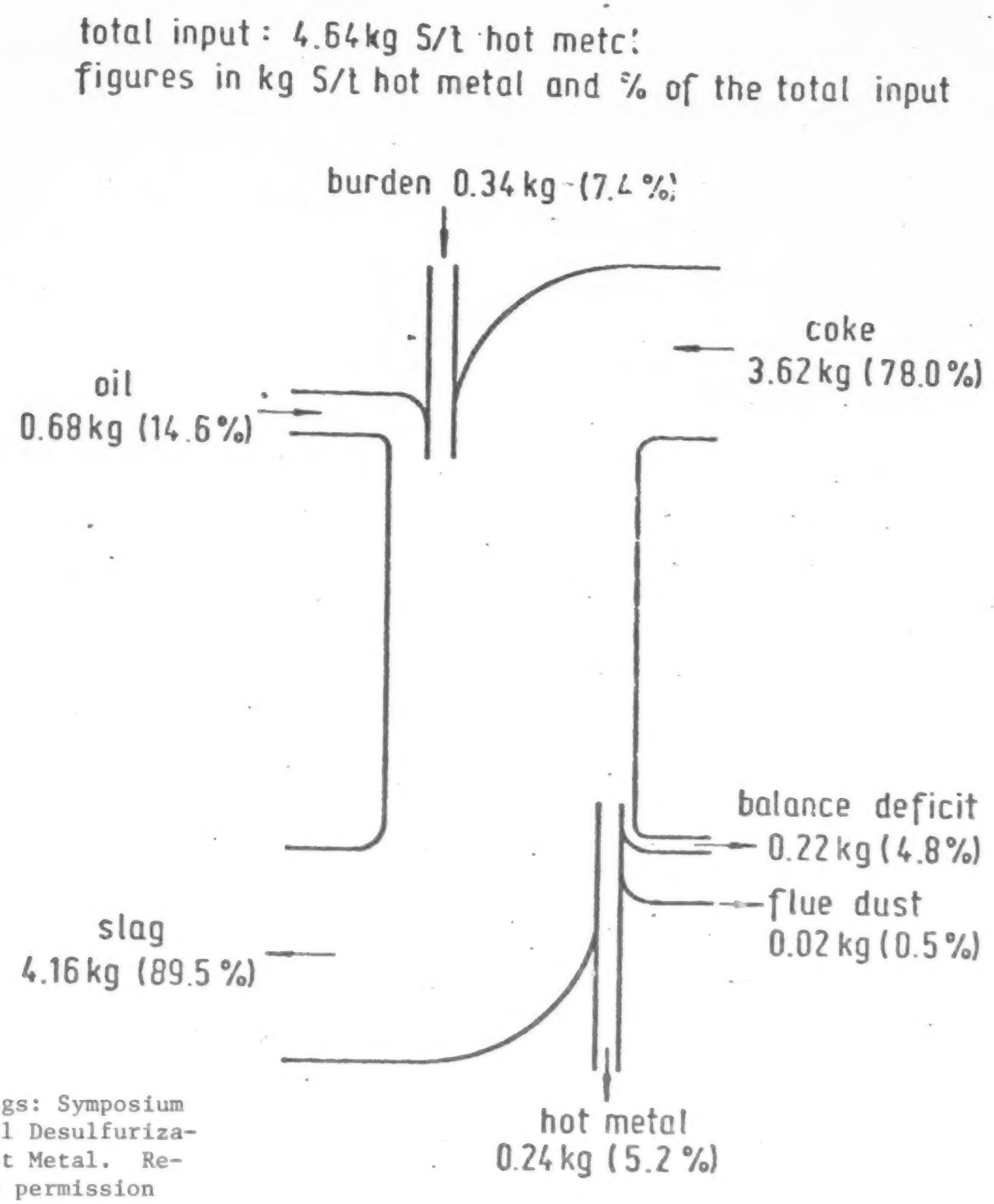
There are many desulfurizing techniques and reagents available: calcium carbide injection, magnesium-aluminum injection, mag-coke plunging, etc. Each technique has its advantages and disadvantages in respect to method of control, method of operation and operating costs. All are able to effectively reduce the sulfur content of molten iron to acceptable levels.

A blast furnace, when operating in conjunction with external desulfurization of iron, can operate with a lean slag. In a typical situation, this type of operation results in a 10 percent decrease in slag volume, a 6 percent decrease in coke rate, and a 37 percent decrease in flux and a 9 percent increase in production.

The operation of the blast furnace with leaner slag and higher sulfur in the iron results in a number of environmental advantages. The furnace operation is smoother, giving rise to fewer emission-causing slips, fewer casting emissions, and lower slag volume. Because the coke rate is reduced, there is a secondary advantage in regard to emissions and environmental problems in the coke ovens. In addition, there is conservation of raw material in terms of fluxes and coal. Figure 26 shows the sulfur balance in a typical blast furnace in which it will be noted that 78 percent of the sulfur comes from the coke and 15 percent from injected fuel oil.

The process for externally desulfurizing iron involves the consumption of reagents such as those mentioned above and the production of dust and slag. However, these are minor in comparison to the savings in the blast furnace, being on the order of 7 to 10 percent. On balance, the environmental effects are definitely on the positive side.

A number of methods are available which are easy to operate and which insure positive control of sulfur levels in the iron. One method, as shown in Figure 27, consists of loading a plunger with Mag-coke^R and dropping it into a ladle which is filled with molten iron. Plunging time is about 15 minutes. Another method (Figure 28) involves the pneumatic injection of the reagent through an injecting lance into the molten iron. The carrier gas for the reagent is an inert gas such as argon or nitrogen. In both methods, it will be noted that a baghouse is provided for the collection of emissions.



(Proceedings: Symposium on External Desulfurization of Hot Metal. Reprinted by permission McMaster University.)

Figure 26. Sulfur balance for a typical blast furnace.

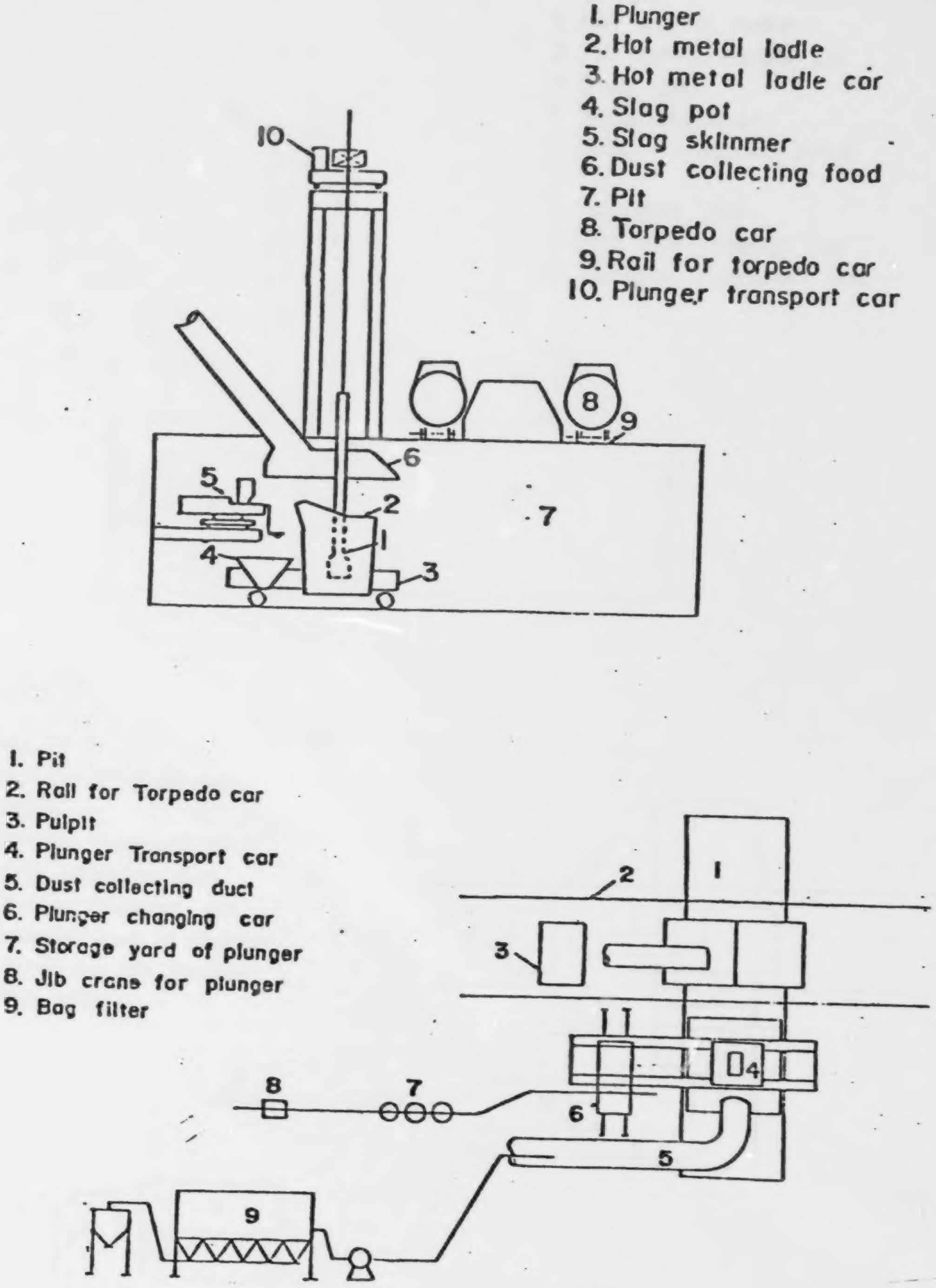


Figure 27. Ground plan of Mag-Coke® desulfurizing plant.

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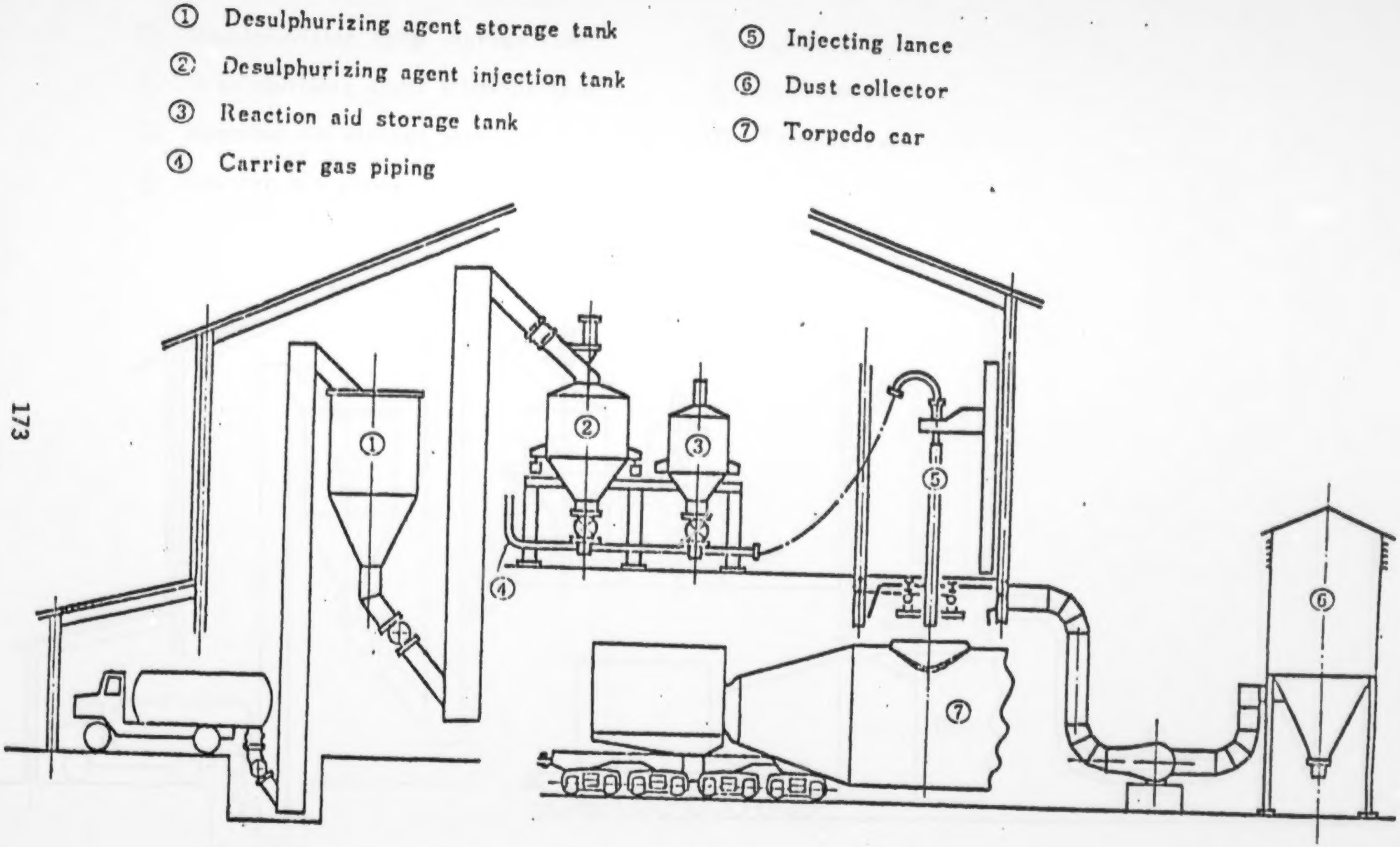
① Desulphurizing agent storage tank
② Desulphurizing agent injection tank
③ Reaction aid storage tank
④ Carrier gas piping
⑤ Injecting lance
⑥ Dust collector
⑦ Torpedo car
①
②
③
④
⑤
⑥
⑦

Figure 28. Schematic representation of the desulfurizing facilities of the torpedo-top-injection method.

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Interest in external desulfurization of iron is rapidly increasing because of its ability to improve iron composition and to reduce operating cost. There is no doubt that the coming decade will see substantial introduction of this method in the steel industry.

Direct Reduction of Iron (DRI)

In the United States, the principal direct reduction process is the Midrex. Figures 29 and 30 show schematic flow diagrams of this process. In it, the oxide feed which is normally lump ore and unreduced pellets flows continuously down through the reduction furnace. The reformed gas has the following approximate composition: 73 percent hydrogen, 16 percent carbon monoxide, 7 percent carbon dioxide, and 4 percent methane. It reacts with and reduces the iron oxide in the reduction furnace. The reduced iron has about 92 to 93 percent metallization and 1 to 1.4 percent carbon.

There are other direct reduction processes on the North American Continent. The HyL process also uses reformed gases. Unlike the continuous process previously described, it is a semi-batch process in which the ore is contained in fixed beds with a multiple number of reactors. Another process is the SL/RN process in which carbonaceous material is mixed with the iron oxide material to form pellets. After preparation, the pellets flow through a rotary kiln reactor and then to a rotary cooler from which they are discharged to magnetic separation facilities. For all of the processes mentioned above, there is emissions control from material handling by means of baghouses and from the circulating gas by means of scrubbers.

In general, the quantity of emissions and wastes produced by DRI are low in comparison to other metallurgical processes. The quantity of dust and sludge is approximately 3 to 6 percent of the feed material. In most plants this is too small for economic recycling and the dusts and sludges are either landfilled or sold to other users.

The reduced pellets, also called sponge-iron, is generally used as charge material for the EAF where it replaces scrap. The result of this replacement is increased consumption of electricity. However, this is balanced by increased yield, increased productivity, and reduction in residual elements in the finished product. There is also an increase in the slag volume as compared to

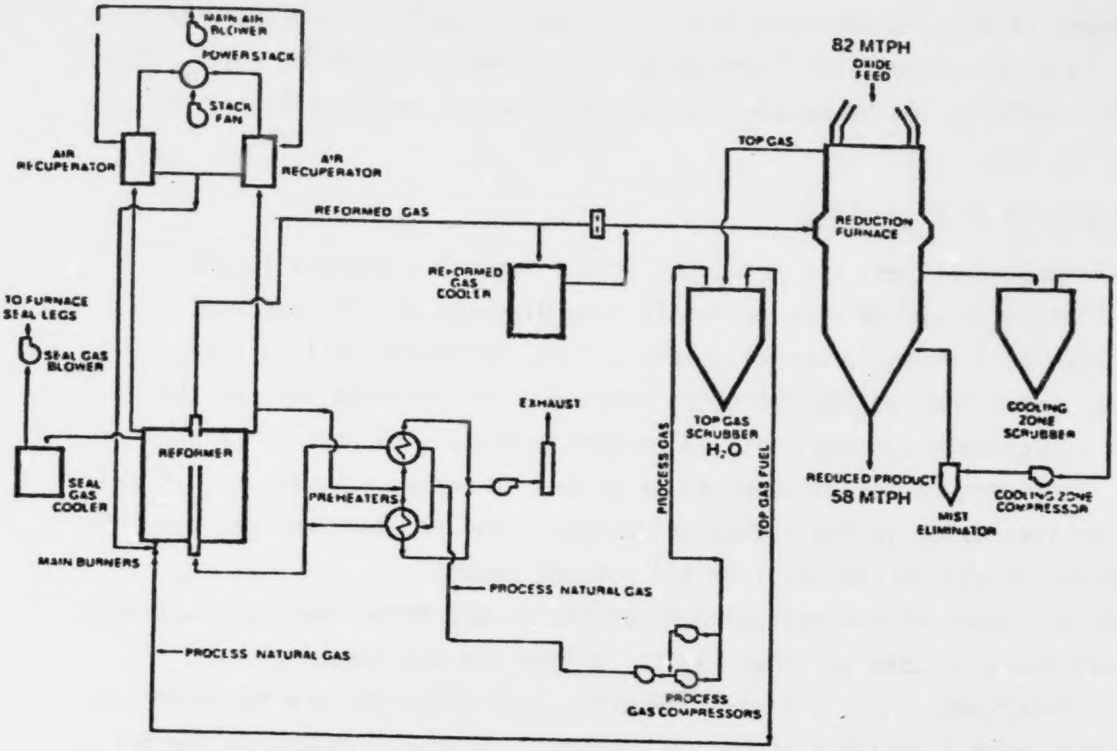


Figure 29. Schematic flow diagram of the Midrex Process.[96]
(*Iron and Steel Engineer*, September 1978)

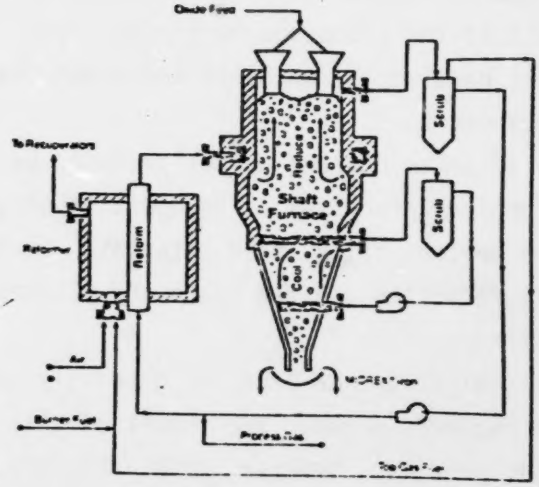


Figure 30. Flowsheet of the Midrex Process.[96]
(*Iron and Steel Engineer*, September 1978)

all scrap practice, the value being approximately equal to that from the BOF. Typical values are shown in Table 72.

TABLE 72. USE OF DIRECT REDUCED PELLETS IN EAFs

1.	Feed scrap, %	100	70	40	20
2.	Feed pellets, %	0	30	60	80
3.	Energy used by furnace kwh/t	541	575	604	635
4.	Yield of steel, %	87.9	89.5	92.6	92.2
5.	Productivity	Base	+8.3%	+7.8%	-2.2%
6.	Residuals, %	0.46	0.57	0.27	N/A

At two installations in Japan, a process similar to the SL/RN is used for recycling iron oxide wastes which are recovered in pollution equipment elsewhere in the steel works. The Japanese report no problem with the presence of zinc or lead and they also indicate that at least part of the product is used as feed for the blast furnace where it results in increased productivity and reduced consumption of coke. Reported values are an 8.2 percent increase in production and reduction in coke consumption corresponding to a 10 percent addition of reduced pellets to the burden.

In the integrated production of steel from iron ore, the direct reduction/ EAF route has the following environmental advantages in comparison to the conventional coke oven-blast furnace route.

1. DRI eliminates the need for coke ovens and all the environmental problems associated therewith.
2. Control of DRI emissions is relatively easy to accomplish.
3. The slag production from DRI comes solely from the EAF. All of the slag from the blast furnace is eliminated.
4. DRI may be accomplished by a wide variety of fuels, thereby avoiding dependency on metallurgical coals.

Direct reduction of iron ore is practiced more widely on other continents than in North America (Table 73). There are only three installations in the U.S. and their total production amounts to somewhat less than 1 million tonnes

TABLE 73. DIRECT REDUCTION INSTALLATIONS IN NORTH AMERICA

Process Name	Location	ANNUAL OUTPUT MT United States	Other
Hoskin	Rockwood, TN	90,000	
Midrex	Georgetown Steel	410,000	
	Oregon Steel	410,000	
	Sidbec-Dosco, Can.		>1,000,000
Accar	Sudbury, Ont. Can.		340,000
HyL	HYLSA(1M)-Monterey, Mex.		95,000
	HYLSA(2M)-Monterey, Mex.		270,000
	HYLSA(3M)-Monterey, Mex.		450,000
	TAMSA-Veracruz, Mex.		235,000
	HYLSA(1P)-Puebla, Mex.		315,000
	HYLSA(2P)-Puebla, Mex.		700,000
Hogannas	New Jersey	70,000	
SL/RN	Stelco, Can.		520,000
TOTALS		980,000	3,925,000

per year. Thus, it accounts for approximately 0.8 percent of the ingot tonnage in the United States.

The development of DRI has taken place primarily in those parts of the world where natural gas is plentiful and cheap and coking coal is essentially absent. Table 74 provides a listing of some of the key factors that affect the development and implementation of DRI. The first column lists those factors that are impeding the development and the second column those which are promoting it. With the passage of time, the impetus to DRI will increase primarily due to the impact of lower capital costs and to the development of DRI processes which will use coal in preference to natural gas as the fuel. Table 75 shows direct reduction plants and plans world wide. It will be noted that North American capacity is expected to triple by 1985.

TABLE 74. IMPLEMENTATION AND DEVELOPMENT OF DIRECT REDUCTION (DR) PROCESSES

Impeding Factors

1. Steel industry conservatism
2. High development costs
3. Limit and cost of natural gas
4. Low scrap prices versus DR iron
5. DR iron requires more power than scrap in EAF
6. DR iron has higher gangue--leads to high slag in EAF and higher loss of FE
7. Not all ores are suitable for DR

Promoting Factors

1. DR/EAF route has lower capital cost than CO/BF/BOF route
2. DR iron produces lower residuals and faster heats in EAF than scrap EAF
3. DR/EAF has minimal environmental impact compared to CO/BF/BOF

TABLE 75. REGIONAL DISTRIBUTION OF DIRECT REDUCTION PLANTS AND PROJECTS (Thousands of tonne/yr)^{96}

	1954 to 1975		1976		1977		1978		1979		1980		1981 to 1985*	
Region	tonne	%	tonne	%	tonne	%	tonne	%	tonne	%	tonne	%	tonne	%
North America	1970	25.8	2210	25.1	2935	19.5	2935	15.8	2935	11.3	2935	9.4	6455	12.5
Latin America	2400	31.4	3130	35.5	4825	32.1	5345	28.8	8645	33.1	9065	29.2	15035	29.1
Western Europe	810	10.6	850	9.6	850	5.7	1650	8.9	1650	6.3	3650	11.7	5700	11.0
Eastern Europe	—	—	—	—	—	—	—	—	2500	9.6	5000	16.1	5000	9.7
Middle East	—	—	—	—	3015	20.1	4415	23.8	4415	16.9	4415	14.2	8715	16.8
Africa	1150	15.1	1150	13.1	1450	9.6	1700	9.1	1700	6.5	1700	5.5	5100	9.9
Asia	1194	15.6	1344	15.3	1834	12.2	2409	13.0	4134	15.8	4134	13.5	4194	8.1
Oceania	120	1.5	120	1.4	120	0.8	120	0.6	120	0.5	120	0.4	1520	2.9
World total	7644	100	8804	100	15029	100	18574	100	26099	100	31019.	100	51720	100
Distribution by number of installations														
North America	8	23.5	9	23.1	11	21.6	11	19.0	11	17.7	11	16.7	16	15.8
Latin America	8	23.5	10	25.6	14	27.4	16	27.6	18	29.0	19	28.8	33	32.7
Western Europe	7	20.6	8	20.5	8	15.7	9	15.5	9	14.5	11	16.7	15	14.8
Eastern Europe	0	—	0	—	0	—	0	—	1	1.6	2	3.0	2	2.0
Middle East	0	—	0	—	3	5.9	5	8.6	5	8.1	5	7.6	9	8.9
Africa	2	5.9	2	5.1	3	5.9	4	6.9	4	6.5	4	6.0	9	8.9
Asia	8	23.5	9	23.1	11	21.6	12	20.7	13	21.0	13	19.7	14	13.9
Oceania	1	3.0	1	2.6	1	1.9	1	1.7	1	1.6	1	1.5	3	3.0
World total	34	100	39	100	51	100	58	100	62	100	66	100	101	100

(Iron and Steel Engineer, September 1977)

Preheating Scrap for Steelmaking

Scrap preheating is practiced to a limited extent for steelmaking, both in the EAF and BOF. In the former case, the preheating is accomplished by the combustion of fuels in a unit external to the steelmaking furnace. It, therefore, serves to reduce meltdown time, consumption of electrodes, and consumption of electric energy. in this application, preheating has little or no environmental effects.

In the BOF, scrap preheating is accomplished in the vessel. Fuel, either oil or natural gas and oxygen are delivered to the furnace from nozzles of an auxiliary lance. Combustion takes place raising the scrap temperature to red heat. This method of scrap preheating takes time in the furnace and reduces productivity. However, the thermal energy provided in scrap preheating permits greater utilization of scrap. In the BOF under normal practice the metallic charge is approximately 30 percent scrap and 70 percent molten iron; under scrap preheating, the ratios are 40 and 60 percent.

Scrap preheating in the BOF produces essentially no increase in emissions or solid waste as compared to the conventional practice without preheat. However, it does reduce the amount of molten iron which is consumed thereby providing a corresponding reduction in the quantity of emissions and discharges from both the blast furnace and the coke oven.

The main impetus for extension of this practice in the BOF comes from consideration of iron production. If a plant is deficient in blast furnace capacity and if there is extra time available in the BOF, scrap preheating provides an inexpensive way to achieve more steel production. On the other hand, if the BOF does not have the extra time for preheating, it may be more desirable to achieve increased steel production by some other method of increasing ironmaking capacity. Because of these conflicts, it is expected that the implementation of scrap preheating in the BOF will proceed at a moderate pace over the next decades.

Superheating Molten Iron for the BOF

Superheating of molten iron is performed in a furnace which resembles a hot metal mixer. In the lower region of the furnace, jet-flow inductors provide the necessary heat to increase the temperature to any desired level up to 2900°F. The furnace and the 60-Hz inductors have been used extensively for heating molten iron in foundries.

Superheating molten iron serves the same purpose as scrap preheating; that is, to expand the capabilities of existing BOPs without building new blast furnaces or coke ovens. However, it has the advantage in comparison to scrap preheating, that it does not increase furnace cycle time and, therefore, does not reduce productivity of the BOF.

Table 76 shows hot metal, scrap, and other metallic quantities per ton of raw steel under various conditions. In conventional BOP practice (Column A) molten iron comprises about 70 percent of the charge along with 30 percent scrap. If hot metal were superheated 400°F, the added energy would permit melting of about 20 percent more scrap as supplemental coolant, up to about 40 percent of the steel mleted (Column C). The table shows other alternatives such as pre-reduced pellets (Column B), cold pig iron (Column E), etc.

TABLE 76. EFFECT OF SUPERHEAT ON TYPICAL BOF MATERIALS BALANCE AND PRODUCTION[97]

		SUPPLEMENTAL COOLANT			
	Base	Pellets	Scrap	Pellets & Cold Metal	Metal
Superheat temp., °F	---	400	400	400	400
Charge-T/T raw steel	(A)	(B)	(C)	(D)	(E)
Hot metal	0.809	0.791	0.732	0.732	0.681
Scrap	0.340	0.333	0.408	0.308	0.287
Cold metal	---	---	---	0.100	0.186
Pellets	---	0.025	---	0.012	---
Total metallics	1.149	1.149	1.140	1.153	1.154
Steel production rate					
% Base	100	102	110.5	110.5	119
% Maximum	84	86	93	93	100

The advantages claimed for superheating molten iron are that it provides added steelmaking capacity at low cost, it improves scheduling in the BOF and provides a buffer for smoothing out variations in iron composition. At the present time, there are no installations of this technology which operate in conjunction with the BOF. However, it is widely used in iron foundries and is, therefore, considered proven technology. It is expected that the advantages of this practice will result in its acceptance by the steel industry, the rate of acceptance being impeded by that industry's traditional conservatism.

Replacement of Open Hearth Furnaces

In 1977 (see Table 14, Section 6.2.1) the production of steel from the open hearth accounted for approximately 16 percent of the steel output in the U.S. It is expected that this production will gradually diminish over the next two decades due to environmental pressures and operating cost disadvantages in respect to the BOF which would replace it.

The principal environmental problem for the more modern open hearth furnace is the extreme difficulty of controlling fugitive emissions from the furnace during the various stages of charging, melting, refining, and tapping. The cost disadvantages result primarily from the multitude of open hearth furnaces in a typical installation in comparison with the highly controlled, highly productive BOF. Nevertheless, the rate of replacement is bound to be gradual because the more modern open hearth furnaces are relatively efficient and their replacement cost is becoming greater all the time.

The BOF produces less slag (minus 40 percent) and more iron oxide particulates (plus 50 percent) per ton of steel than does the open hearth furnace. In 1977, if all of the open hearth capacity had been replaced by BOF capacity, the change in production of solid waste would have been a slag reduction of 1930 tonnes and an increase in iron oxide of 130 tonnes.

Continuous Casting

There are two methods of producing semi-finished product in operation today. One is to pour the steel into ingot molds, strip the ingots from the molds, reheat them in soaking pits and roll them on a primary mill. The other is to pour the steel in a water-cooled copper mold that is open at the top and bottom. The shape of the mold is such as to directly produce the semi-finished product which is withdrawn continuously from the open bottom.

The quality of continuously cast steel is equal to that of conventionally made steel, and often better. The yield of the semi-finished product as compared to the ingot route is higher, the manhour requirements are lower, the energy requirements are significantly reduced and the use of plant space is more efficient.

Because of these advantages, continuous casting has been making inroads into steelmaking technology. Starting with the first U.S. installation in 1962, by 1969 U.S. production was 4.5 million tonnes of continuous cast steel and by 1978, 28.4 million tonnes. It is estimated that there is a potential for continuous casting in the U.S. of about 75 million tonnes.[98] It is not unreasonable to project that nearly all of this capacity will be provided within the next two decades.

The yield of semi-finished steel from molten steel varies depending upon the nature of the final product whether slab, bloom, etc. On the average, the yield from continuous casting is 94 percent, and from the ingot route 81 percent. The scrap loss in the ingot route is 13.5 percent and in the continuous casting route 5.1 percent. The loss in terms of scale and sludge are 5.2 percent and 0.8 percent, respectively. The latter change is particularly significant since a portion of scale and sludge is landfilled or dumped and thus irrevocably lost to the steelmaking process.

The environmental advantages of the continuous casting route in terms of reduced emissions to air and water and reduced solid waste generation go beyond the immediate process itself. Because the molten steel is used more efficiently, to produce the same volume of finished product, less steel needs to be made in the steelmaking furnace, less iron in the blast furnace, and less coke in the coke plant. Each of these changes has its own environmental benefits.

8.2.5 Effect of Process Changes on the Model Plant

In the previous section, descriptions were provided for various process changes that affect the generation of solid waste and the utilization of resources. In order to quantify the potential effects and to put the value of the changes in proper prospective, it is necessary to incorporate them in the model plant of Section 6.0.

The model plant of Section 6.0 provides information on the generation of solid waste from a production of 2,500,000 tonnes of steel per year. In this plant the production of semi-finished steel is 2,140,000 tonnes per year. In order that a fair evaluation of the process changes be made, and because some of the changes reflect variations in yield, the production of semi-finished steel has been held constant. The production figures from the various units preceding this point were then derived by working backwards through each of the processes. In the various diagrams which follow there are two values of quantity shown for each item. The value without parentheses is the original value before implementation of the process change; the value in parentheses is after the process change.

The results which are shown in the diagrams must be treated with caution. The quantities shown derive from a number of simplified assumptions. They ignore the complications that pertain to implementation of process changes in existing facilities where, for example, an otherwise desirable change is impeded by existing technology, space limitations, lack of capital, company conservatism, etc. Despite the caution, the results do indicate that the process changes have the capability of making substantial reductions in the generation of solid waste and that they deserve further investigation.

Analysis of Process Changes

Each of the process changes described in the preceding section will be inserted into the model plant and its effect on resource consumption and solid waste generation will be analyzed.

Figure 31 shows the effect caused by further implementation of continuous casting. The assumption is made that semi-finished steel produced in this manner will essentially double and thereby provide two-thirds of the product. The effect on input of molten steel is to reduce the quantity by 4 1/2 percent. The reduction is distributed on a percentage basis between the BOF and EAF. The amount of scrap produced is reduced by 71,500 tonnes and this is reflected in the charge to two melting units.

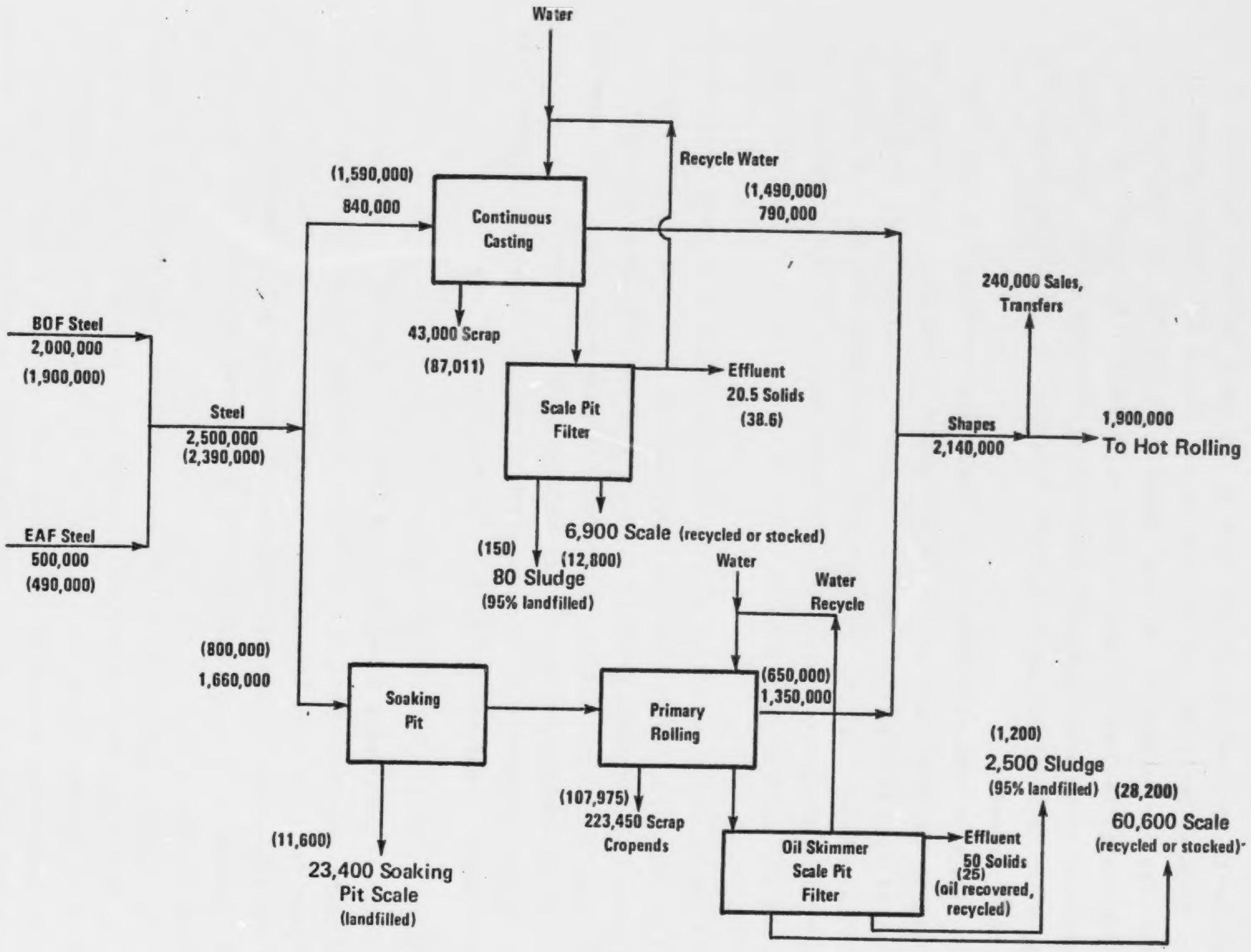


Figure 31. Continuous casting, soaking, primary rolling material flow in production of 2,500,000 tonnes of steel per year (all numbers in tonnes). 16 (numbers in parentheses represent results of process changes)

Figures 32 and 33 show the material flow to the EAF and BOF, respectively. In these units, pre-reduced pellets make up the scrap deficit, the ratio of pellets to scrap being the same in both units. In the EAF, other changes in dust and slag are ratioed to the steel output. In the BOF the situation is more complicated in that not only is this ratio taken into account but also the effect of scrap preheating and superheating of molten iron. These last two cause the ratio of hot metal to total metallics in the charge to drop from 70 to 56.4 percent.

In Figure 34, the reduction in iron requirements reduce the demand for materials in the blast furnace and the production of wastes. In addition, the quantity of slag is reduced another 10 percent in response to the introduction of external desulfurization. Further, the coke requirements are estimated at 500 kg/MTHM which assumes substantial implementation of burden preparation, a high rate of fuel injection and dehumidification of the blast throughout the industry.

Figure 35 shows the effect on coke oven operations that takes place as a result of the reduction in coke requirements. The amount of coal required, the by-products and waste produced all vary in proportion to coke output.

Figure 36 combines all of the process into one model plant. The combined effect of the various process changes becomes evident. There is substantial change in the quantities of resource material that is required and wastes that are generated. These are analyzed in the next two sections.

Analysis of Resource Consumption

Table 77 provides a summary of the amount of resource material as well as solid waste generation that is required both before the process changes are initiated and after they take place. In addition, there are two columns which show the difference in material requirements, both as actual tonnes per year and as percent of initial requirements. All of the quantities are taken from the data in Figure 36.

The iron ore quantities include charge material from the blast furnace as well as that for direct reduction. There is a slight increase in ore consumption (2 percent) which results from the introduction of direct reduction less the cumulative effects of continuous casting, scrap preheating, and superheating of molten iron. On the other hand, the quantity of scrap consumed

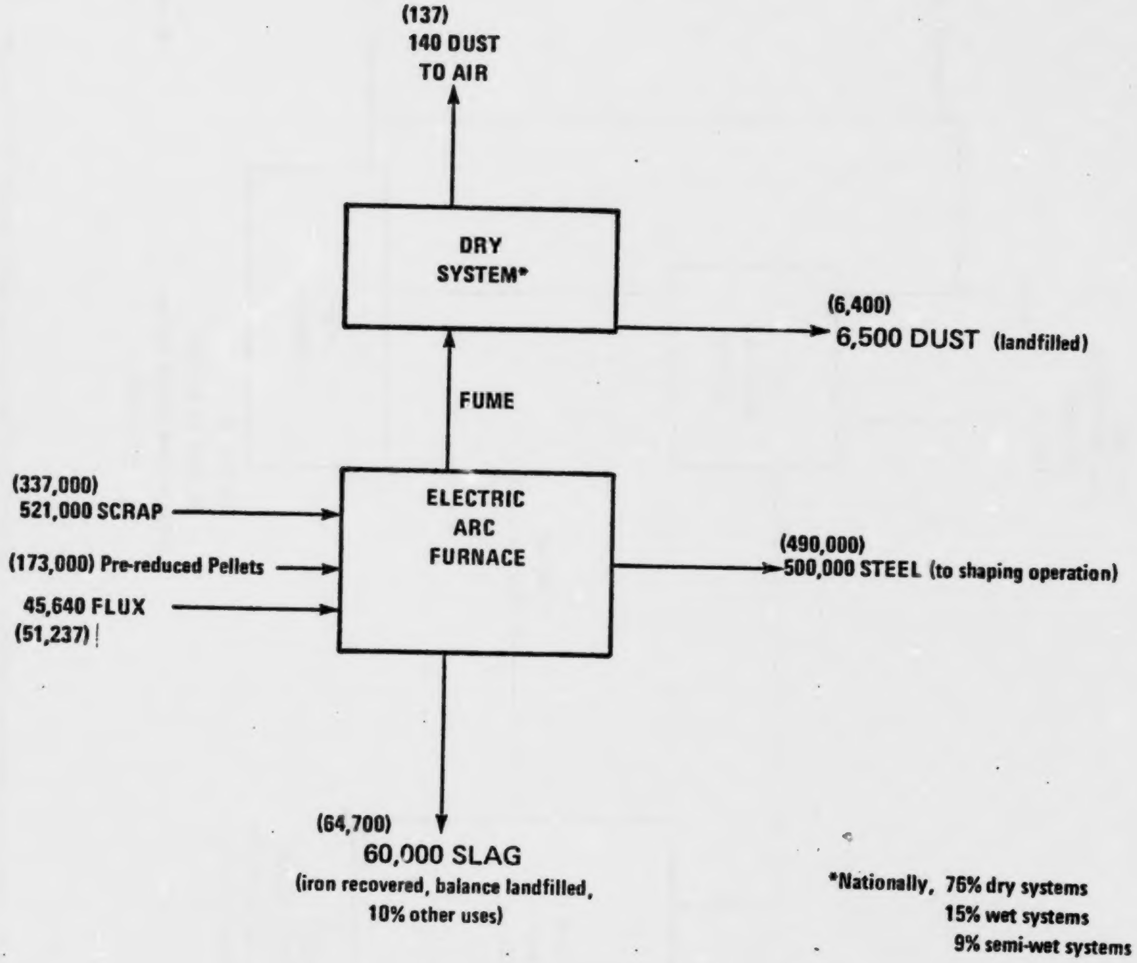
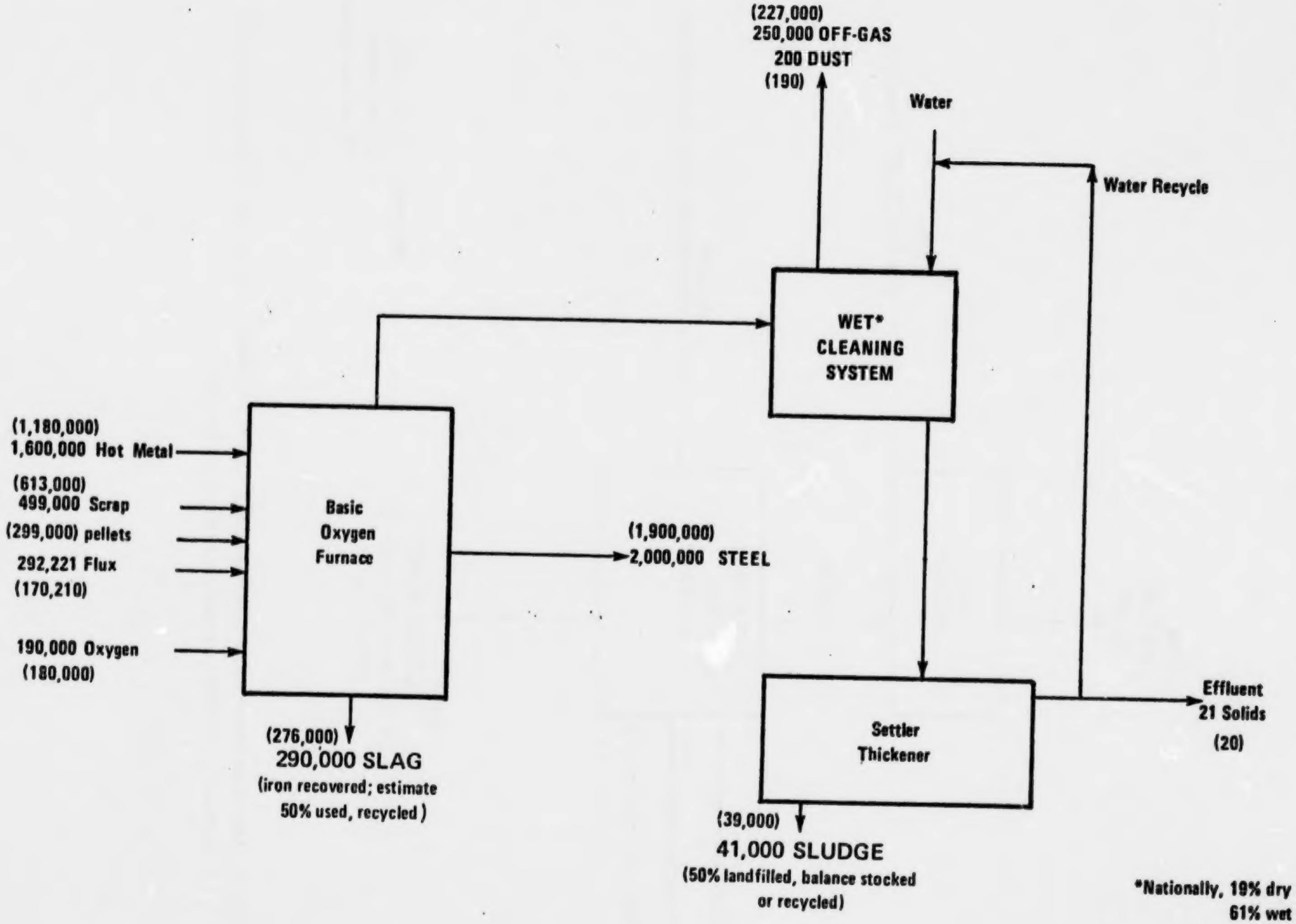


Figure 32. Electric arc furnace material flow in production of 500,000 tonnes of steel per year (all numbers in tonnes). (numbers in parentheses represent results of process changes).



*Nationally, 19% dry systems
61% wet systems
20% semi-wet systems

Figure 33. Basic oxygen process material flow in production of 2,000,000 tonnes per year of steel (all numbers in tonnes).[16] (all numbers in parentheses represent results of process changes)

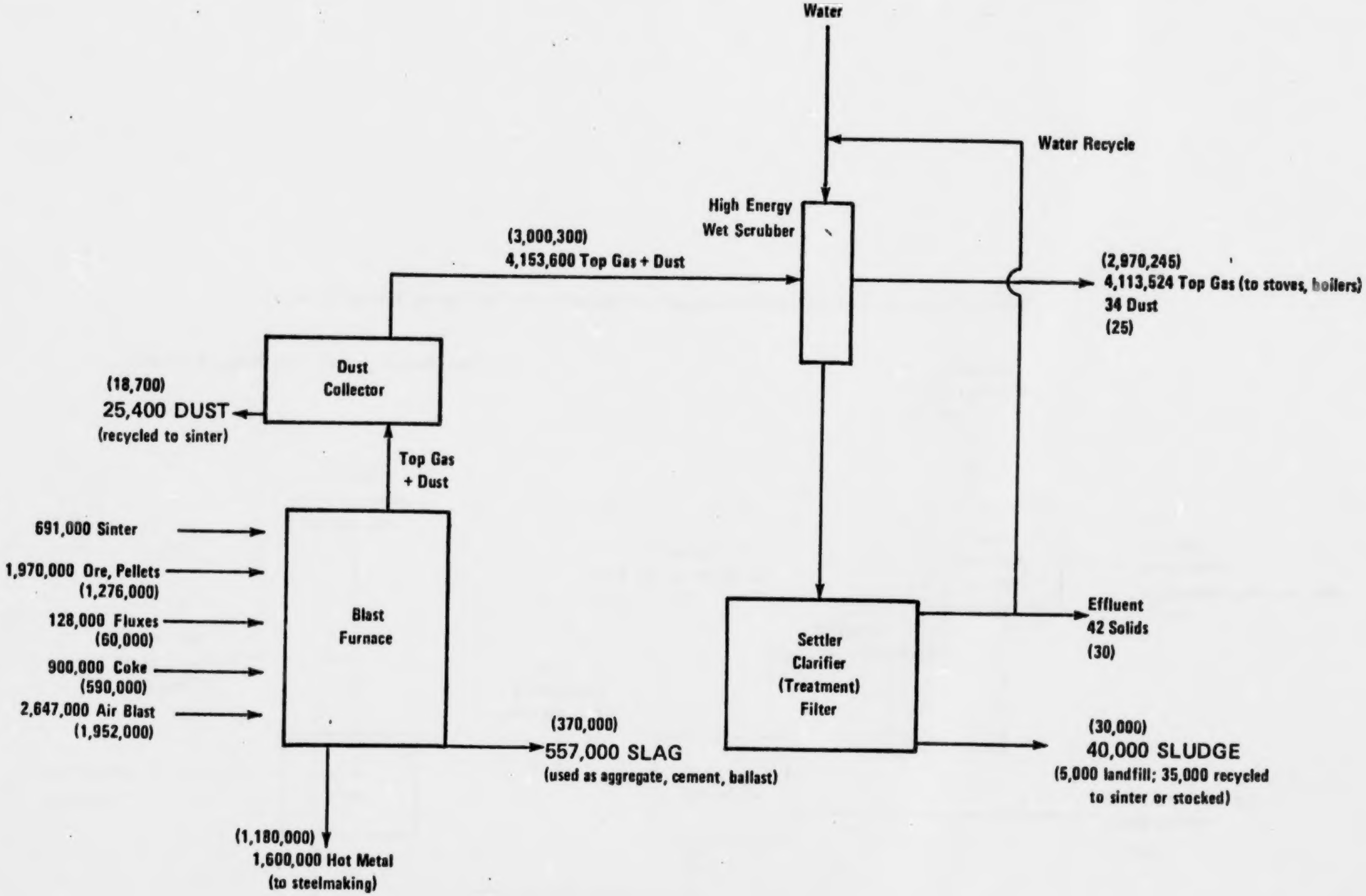
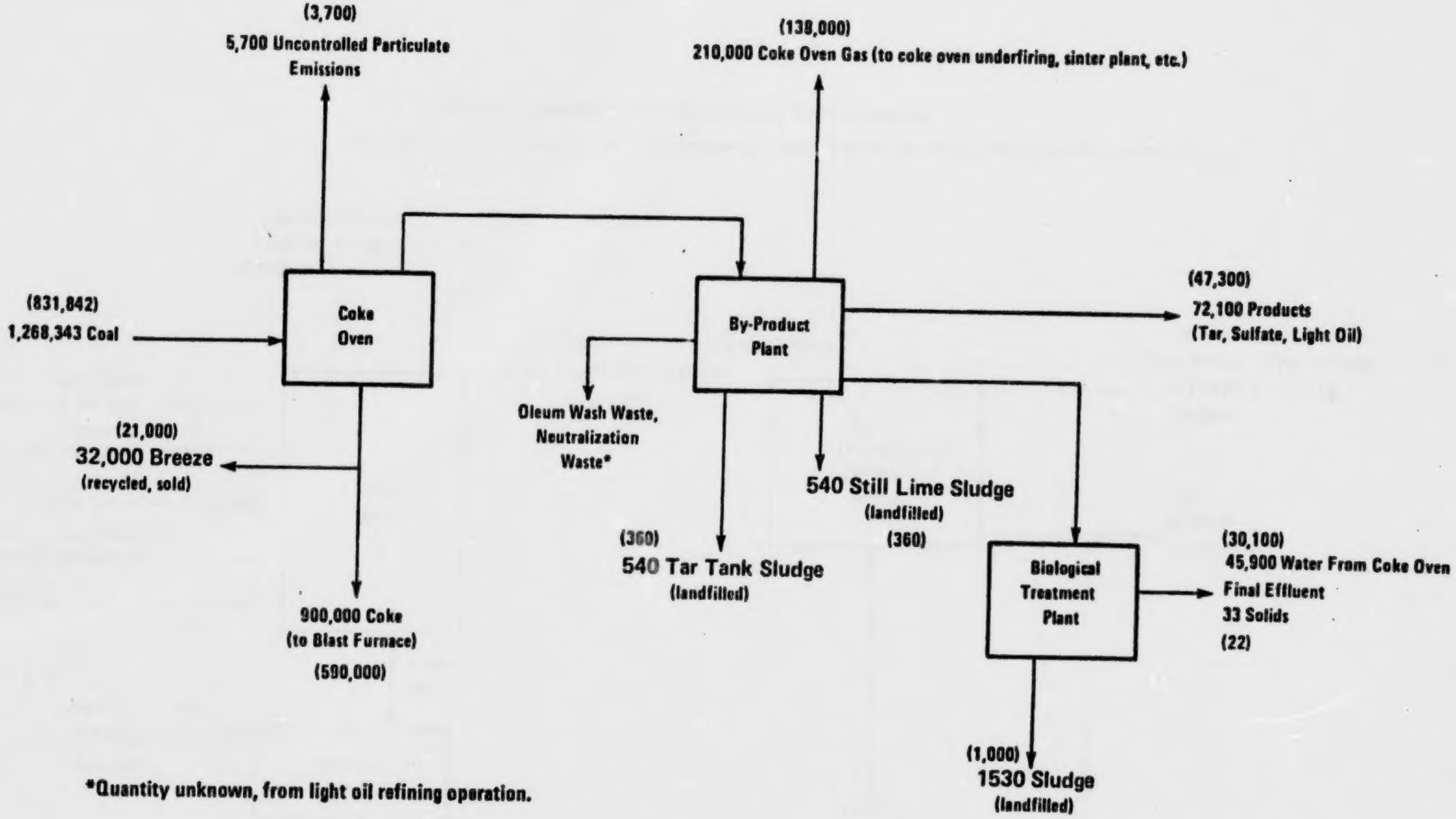


Figure 34. Blast furnace material flow in production of 2,500,000 tonnes of steel per year (all numbers in tonnes).[16,18] (numbers in parentheses represent results of process changes)



*Quantity unknown, from light oil refining operation.

Figure 35. Material flow for coke plant in production of 2,500,000 tonnes of steel per year (all numbers in tonnes).[1]

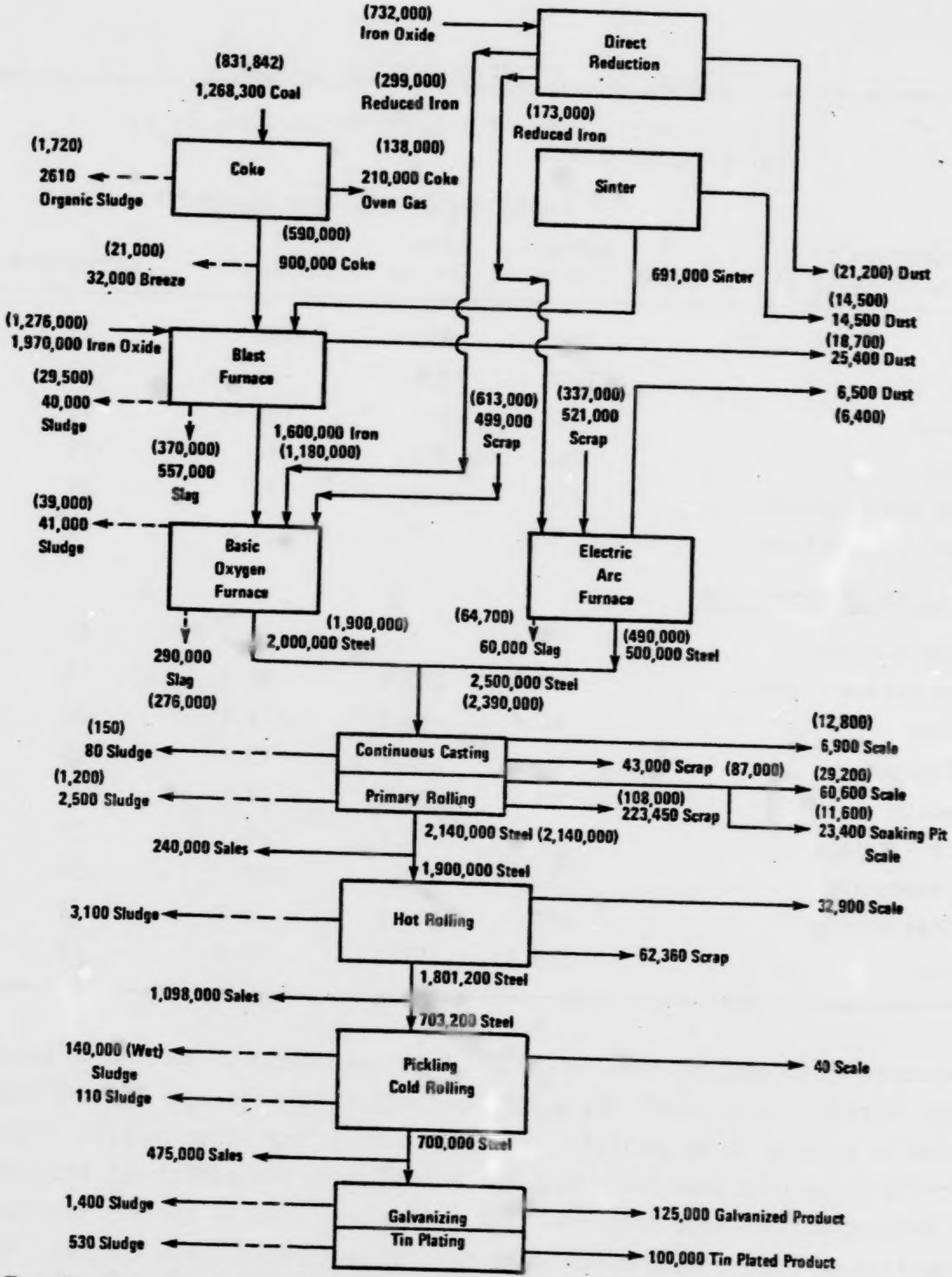


Figure 36. Waste production from typical plant with 2,500,000 tonnes of steel per year (all numbers in tonnes). (All numbers in parentheses represent results of process changes.)

TABLE 77. EFFECT OF PROCESS CHANGES

Model plant to produce 2,140,000 tonnes annually of semi-finished steel

Consumption of Resource Material	ANNUAL QUANTITIES-1000 TONNES/YR Before Change	After Change	Difference	% Difference
Coal	1268	832	436	35
Iron ore	1970	2008	-38	- 2
Fluxes	466	281	185	39
Scrap	499	613	-114	-23
Coke gas produced	210	138	72	35
Light oil produced	72.1	47.3	24.8	35
Solid Waste Generation				
Organic sludge	2.6	1.7	0.9	35
Iron oxides - total	257.5	220.9	36.6	14
Dust	46.4	60.8	- 14.4	-31
Sludge	87.3	73.6	13.7	16
Scale	123.8	86.5	37.3	30
Slag - total	907	710.7	196.3	22
Ironmaking	557	370	187	34
Steelmaking	350	340.7	9.3	3
Scrap	328.8	257.4	71.4	22

increases by 23 percent as a result of these same factors, continuous casting acts to reduce scrap while the other two factors increase it. The additional scrap is assumed to be available from purchases in the scrap market. Any shortfalls in this area would have to be made up by the additional production of reduced pellets from iron ore. The reduction in fluxes derives from the reduction in steel requirements which take place in continuous casting. However, the largest reduction takes place in the blast furnace because of the widespread introduction of external iron desulfurization. The reduction in coal essentially reflects the cumulative benefits of process changes which were introduced in the blast furnace, BOF, and continuous casting.

Listed under resource material are the by-products produced in the coking operation. The principal ones, coke oven gas and light oil, are reduced in production by the same percentage that applies to the reduction in the consumption of coal. They are considered resource material because they supply energy that otherwise might have to be furnished from another source.

Analysis of Solid Waste Generation

The reduction in the generation of solid waste as a result of the process changes previously described follows a similar pattern to the reduction in the consumption of resource material. The generation of organic sludge, for example, drops by the same percentage as does the reduction in coal consumption. A similar comparison exists between total slag and fluxes. Iron oxide wastes drop by a somewhat smaller percentage than the previous factors.

In regard to scrap, there is a substantial change that occurs. Before the initiation of the process changes the amount of scrap consumed exceeds that produced by 170,000 tonnes. After the process changes are in place, the difference increases by 2 times to 355,000 tonnes. In order to achieve balance, much more scrap will have to be purchased under the latter condition than under the former. On balance, this is undoubtedly a positive environmental factor because it will provide incentive for increased efforts in the recovery of scrap and in the regulations of its export.

The process changes also create another positive environmental effect in regard to solid waste generation. As will be noted on Table 77, the generation of the waste in the form of sludge decreases by almost the same amount as the increase in dust generation. Since dust is generally easier to handle than sludge and since its handling does not incur the water pollution problem that accompanies sludge handling, environmental degradation will be reduced.

8.2.6 Future Iron and Steelmaking

The iron and steel plant of the future may incorporate radically new technologies for producing steel. A method for producing the molten steel directly from iron oxide, coal, and oxygen has been proposed and described earlier in this report as well as shown in Figure 25. There was also discussion of powder stripmaking in which the molten steel is converted to a powder which is compacted and rolled into sheet steel. These two technologies, in combination, would offer reduction in the physical size of the plant, its capital and operating cost and the environmental effects. It is relatively easy to visualize how these processes may be essentially closed to prevent emissions to the atmosphere, and how they may reduce solid waste generation. As noted before, the implementation of these and other technologies will probably not take place until the next century. It would certainly be of benefit to the steel industry and to the environment if the Federal Government were to provide incentives for their development.

There is one case where the steel plant of the future appears to be under construction today in Pittsburgh.[99] This is a plant designed to produce 20 to 25 TPH of light product such as rebar, rounds, and other merchant products.

Figure 37 shows a diagram of the process. In it, scrap is charged to an EAF from which the molten steel is poured into an 8 foot wheel-belt caster. From the casting machine the semi-finished bar proceeds through a 14-stand rolling mill, a looper, and a cooling conveyor. Figure 38 shows the section for the as-cast billet, the intermediate shapes and the finished round. The remarkable feature of the mill is that the entire facility, including melting, casting, and rolling takes place within a space of about 200 square feet.

8.3 NEW DIRECTIONS SUGGESTED BY RECENT U.S. PATENTS

The patent classes and subclasses that were searched for this discussion are as follows.

Class 65	Glass Manufacturing
/19	Slag utilization
Class 75	Metallurgy
/3	Beneficiation of ores by agglomeration
/4	Beneficiation by coking
/5	Beneficiation by sintering
/24	Pyrometallurgy, treating slag
/25	Pyrometallurgy, treating flue dust
/30	Pyrometallugy, iron/steel slags

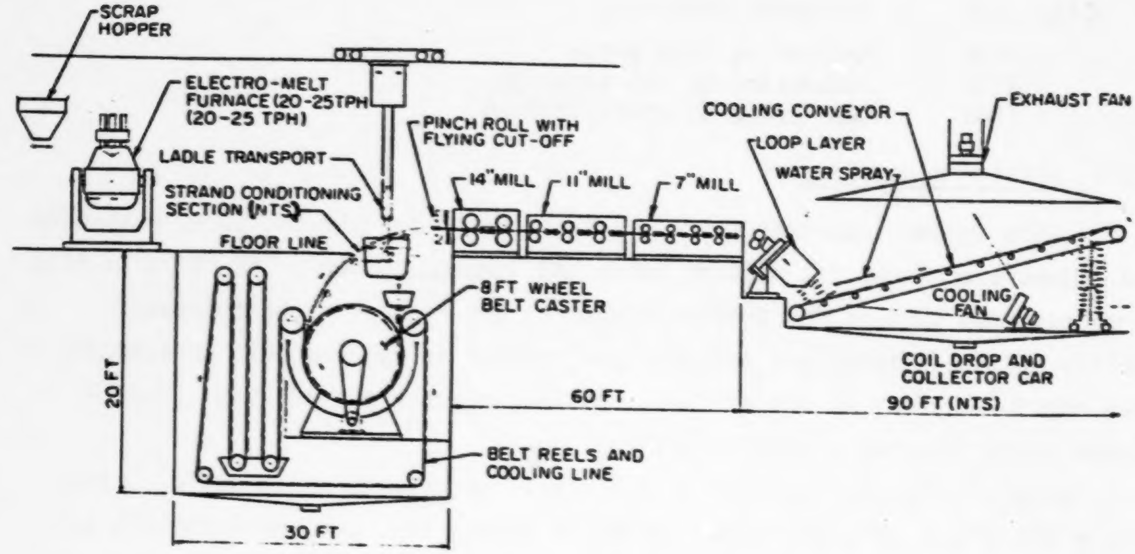


Figure 37. Melt shop, caster, rolling mill layout for 100,000 ton per year facility.[99]
(*Iron and Steel Engineer*, September 1978)

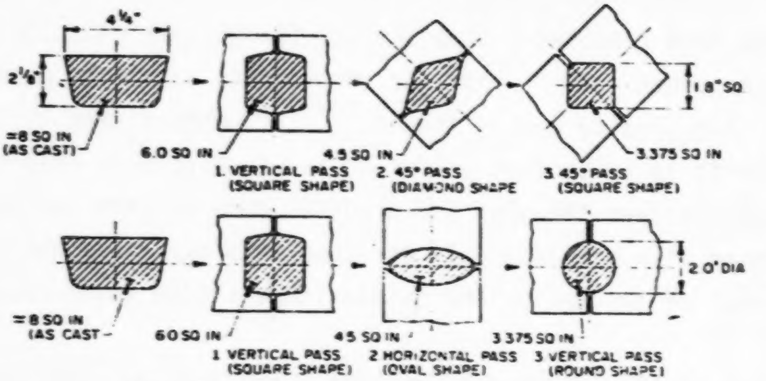

4¼"
2⅛"
≈8 SQ IN (AS CAST)
6.0 SQ IN
1. VERTICAL PASS (SQUARE SHAPE)
4.5 SQ IN
2. 45° PASS (DIAMOND SHAPE
1.8" SQ
3.375 SQ IN
3. 45° PASS (SQUARE SHAPE)
≈8 SQ IN (AS CAST
6.0 SQ IN
1 VERTICAL PASS (SQUARE SHAPE)
4.5 SQ IN
2 HORIZONTAL PASS (OVAL SHAPE)
3.375 SQ IN
3 VERTICAL PASS (ROUND SHAPE)
2.0" DIA

Figure 38. Cast billet, intermediate shapes, and finished round.[99]
(*Iron and Steel Engineer*, September 1978)

Class 423	Inorganic Chemistry
/138	Recovering iron group
/139	Recovering by ion exchange
/140	Recovering by precipitation

8.3.1 Blast Furnace Slag

This stream comprises waste oxides from the ore and the coke, with lime and magnesia to lower its melting point and take up sulfur. The ratio of slag to molten iron product has trended downward; one reason is the increased quality of beneficiated ore pellets, and another is reduced coke consumption made possible by oxygen and/or fuel additions through the tuyeres. Superfluxed sinter has had a small additional impact.

"External desulfurization" is a process improvement which would further reduce the volume of slag. The concept is hardly new, but new materials or methods may spur its adoption. Thus Turkdogan advocates desulfurization in a first blow in the BOF, and Yoshida recommends oxide-coated magnesium particles.[106,107]

If the slag is poured into a pit and allowed to cool slowly, it is difficult to break up and use. Jablin has proposed dry quenching with heat recovery in a waste heat boiler.[108] But most quenching is with water, and this generates H_2S and a runoff of contaminated water. At least one local control agency (Allegheny Co., Pennsylvania) requires the abatement of this nuisance, and several patents have resulted. Some seek to prevent the emission by adding reagents to the quench water: bases or carbonates, oxidizing agents, and ferrous salts, e.g., waste pickle liquor.[109-112] Others seek to collect the H_2S and oxidize it to by-product sulfur or to water-soluble anions.[114-116] Water quenching shatters the slag and produces more surface and more H_2S; a gentler quenching with air, possibly enriched with oxygen, might be presumed to freeze in most of the sulfur and oxidize that little which appeared at the surface.[117]

In addition to the well-known uses for blast furnace slag, it can be used to stabilize the sludge from lime or limestone scrubbing of flue gases.[119]

8.3.2 Steelmaking Slags

In many cases these have been recycled to the blast furnace to recover iron values. Zinc oxide is added to the slag by the process outlined in the Kreiger patents and may cause problems in recycling the slag to the blast furnace.[104,105] The change in composition of BOF slag, for example, is not large, and a reducing blow in a separate vessel could make it acceptable for immediate recycle to the converter; the slag from an occasional blow might have to be purged.[119,120]

8.3.3 Blast Furnace Dust and Sludge

Blast furnace dust is routinely recycled to the blast furnace by way of the sinter plant; the sludge, being fine and wet, presents a problem. Since some water is necessary in the sinter mix, judicious dewatering of the sludge permits it to be the source of that water. Alternatively, the sintering process may be managed in such a way as to be more tolerant of wet solids.[121]

But there is no doubt that the finest blast furnace dusts and sludges require special handling when used for sinter feeds, and various other means of agglomerating such material to form blast furnace burden have been commercialized over the years. Lime, portland cement, and coal tar pitch are well-known binders, but some thermal processing or at least aging is required.[122] A novel bonding agent is formic acid in aqueous solution; some heavy metal oxides dissolve briefly and then re-precipitate as a gelatinous binder.[122,123] More aggressive thermal treatments, as in rotary kilns, typified by the SL/RN process, are offered commercially. Some of these merely coke the iron oxide and some go as far as direct reduction.

In the current view none of these processes is economical when applied to waste oxide reclamation. But if they were operated at the scale of a formed-coke plant, the view might be entirely different. Thus a plant operated according to an FMC patent admixes a judicious amount of water with the coal char; clearly this water could contain iron oxide fines.[124] Incorporating dry iron oxides was contemplated in an earlier FMC patent.[125] The problem with this method of recycling iron oxide wastes is that, under the reducing conditions which exist in the coke ovens, the sulfur in the coal would react and combine with the iron oxide, thereby adding to the sulfur burden in the blast furnace. This is undesirable.

A PECOR patent discloses that dry or dried waste oxides can be entrained into a blast furnace or Q-BOP through the tuyeres.[126] The expectation is that most of the recycled material would be incorporated into the metal or the slag; any which escaped would serve as condensation nuclei, making the emitted particulate coarser and thus easier to collect.

The finest blast furnace particulate is a nuisance when collected wet or dry. The former is the conventional choice. But two novel processes collect and chemically modify the solids. A patent assigned to Republic Steel discloses that a hot gas stream containing carbon monoxide and iron values should be passed through a bed of granular lime; metallic iron and dicalcium ferrite ($2CaO \cdot Fe_2O_3$) are formed.[127] Such a product is suitable for recycle to the blast furnace. A patent held by Kaiser Steel advocates passing a similar gas through a bed of sufficiently hot coke to yield molten iron, which would be expected to agglomerate.[128]

8.3.4 Steelmaking Dust and Sludge

These solids are not importantly different from blast furnace solids unless the charge includes scrap with a significant fraction of tramp metals, especially zinc and lead. These elements are undesirable in sinter destined for a blast furnace. Some have in the past advocated that all such scrap be rejected. Proper management might confine the tramp metal to a single collection system and to scheduled times, permitting uncontaminated oxides to be recycled. Commercialized systems for purging tramp metals from waste oxides are described in a previous section.

There are alternatives. One advocates using occasional cycles of an EAF to drive off zinc and lead from agglomerates containing waste oxides, limestone, and coal or coke breeze.[129] Others recommend that the waste oxides be leached with acids such as waste pickle liquor, or with ammoniacal solutions such as weak ammonia liquor from the coke by-product plant.[130-132] Some have argued, however, that no process short of complete reduction can adequately decontaminate the waste oxides, because some of the zinc is bound up in stable mixed oxides of zinc and iron.

8.3.5 Rolling Mill Wastes

Mill scale is conventionally recycled directly to the blast furnace, and the finer sludge from the hot rolls usually goes to the sinter plant. When this sludge is contaminated with hydraulic or lubricating oils, the exhaust from the sinter plant is smokey. A patent discloses that the smoke arises near the feed end of the machine and that the smokey exhaust can be routed to another portion of the bed which acts as an incinerator.[133]

Pickling at various stages in the rolling mills was once performed with sulfuric acid; neutralizing the waste acid usually produced an iron-bearing calcium sulfate sludge. Modern practice has largely swung over to hydrochloric acid, and there are commercial regeneration processes for the spent acid. But rinse waters still constitute a problem and neutralization of these with lime produces a difficult suspension of iron values in a salty wastewater. A patented option is to contact the rinse water with an immiscible hydrocarbon solvent, such as light oil in this industry, containing a dissolved amine.[134]

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